N70-10588

RICE UNIVERSITY
Houston, Texas

CONDENSERS AND OR EVAPORATORS IN CONVECTIVE AND RADIATIVE ENVIRONMENTS

D. B. Mackay, Professor
of Aerospace Engineering
G. R. Brown, Student Assistant
Aerospace Technology Report#5
April 1969

CONDENSERS AND OR EVAPORATORS IN CONVECTIVE AND RADIATIVE ENVIRONMENTS

D. B. Mackay, Professor of Aerospace Engineering

G. R. Brown, Student Assistant

Aerospace Technology Report #5

Rice University
Houston, Texas

April, 1969

Prepared under NASA Grant NGR 44-006-033.

ABSTRACT

Two digital programs, Numbers 5-1 and 5-2, for analyzing steady-state performance of heat exchanger systems, are presented. These programs are restricted to systems where the prinicpal source or sink for the heat is attributable to latent heat of the fluid which passes through ducts located in the exchanger. Extended surfaces (fins) to improve the system performance may be attached to the ducts. Heat is exchanged with the environment by radiation, convection, or both. Fluid pressure drop is calculated (for the two-phase flow) by the Lockhart-Martinelli method.

Program 5-1 is restricted to the analysis of circular ducts having two symmetrically located single section fins. The radiation environment may include the effects of three external bodies. One of these is assumed to be the sun. The others can be of almost any shape or size as long as their effect on heat transfer can be expressed by their view factors, surface temperatures and emissivities. These three factors are assumed constant along the length of the duct and along the length of the fin. Fin performance is established by a Runga-Kutta-Gill numerical integration routine.

Program 5-2 analyzes complicated duct and fin configurations. Pressure drops for irregular duct shapes are calculated assuming an effective diameter equal to four times the hydraulic mean radius. Single or multisection fins can be attached to the external surface of the duct. Each fin can have its individual material properties and environments. However, the fin performance must be fed in as input data to the program. Performance of unsymmetrically spaced fins in a radiative environment will need to be approximated since no known exact solutions are available.

CONTENTS

ILLUSTRATIONS

INTRODUCTION

In the performance analysis of condensers or evaporators two major items that have to be evaluated are (1) the radiative and convective heat exchange with environment and (2) the fluid pressure change within the duct. To handle the overall task it was decided to assemble two complete programs. These are numbered 5-1 and 5-2.

This study is a natural follow-up of the work presented in Refs. 1 and 2 in which programs are presented for calculating the combined effects of radiative and convective heat transfer in heat exchangers and surfaces. Techniques have already been developed for predicting the performance of condensers losing heat solely by radiation, see Ref. 3. This study contains the first programs capable of analyzing both condensers and evaporators in convective and radiative environments.

In radiative and convective cases it was observed that the length of duct required to cool or heat a fluid could be established using equivalent length for the fins and duct system. The equivalent length of a fin is defined as the length of an imaginary strip measured perpendicular to the axis of the duct that would transfer the same amount of heat as the actual strip but would have a constant temperature equal to the root temperature. The equivalent length was observed to be nearly independent of the root temperature and would therefore remain essentially constant along the duct.

Program 5-1 analizes configurations employing circular tubes and symmetrical fins. The maximum complexity for the radiative environment is as illustrated in Fig. 1. Program 5-2 analizes complex configurations including multisection fins and non circular ducts. The duct configuration is specified either by the internal diameter or by the cross-sectional area and perimeter. The later option is used for non-circular ducts. The required fin performance item is the equivalent length which can be evaluated by using programs given in Ref. 2. By separating the fin performance calculations from the duct length calculations, innumerable geometric configurations can be analyzed. The fins can be of single or multisection shapes, of unsymmetrical design, of different materials, and even in different environments.

Heat exchanger performance calculations in purely radiative environments given in Ref. 4 were simplified by using dimensionless parameters to specify the environment and the fin configuration. Curve fitting techniques were subseqently employed to correlate numerically calculated data so that the programs contained only systems of curve fit equations to calculate the fin performance. No comparable set of equations is available for calculating the effectiveness of fins in a combination of radiative and convective environment. Therefore, in these programs, numerical integrations are used, either directly or indirectly, to obtain the fin performance.

The heat transfer coefficient from the fluid to the wall is very high when a mixture of liquid and vapor is present. Under these conditions little temperature difference exists between the fluid and the wall and little error is introduced in the programs by assuming the two temperatures are equal.

Two-phase flow in the tubes of a condenser presents a more difficult pressure drop analysis than does a liquid in a radiator. The flow can be in either laminar or turbulent regimes at the tube entrance. In two-phase flow, one of the phases can be turbulent while the other is laminar. Due to condensation or evaporation of vapor the flow regime for either liquid or vapor can change from one to the other. Since all the variations are possible, these programs have been written to evaluate the regime for each fluid, for each section and to calculate the pressure drop in the section assuming the no change or regime takes place within the section. To accurately calculate the total pressure drop in the duct it is necessary to divide the length into a number of short sections. The input data for specifying the problems are the normal conditions encountered, such as tube size, fluid flow rate, and fin geometry. The duct lengths and duct section lengths are established by the programs. The input values for temperature (T^*) and pressure (P^*) for the fluid entering the ducts are assumed to be at saturated conditions. As the fluid flows along the duct the static pressure will either rise or fall. In a condenser for low to moderate flow rates the pressure normally rises since the momentum head is larger than the friction pressure drop. At higher rates the friction pressure drop will become the predominant factor. For evaporators, however, there is always a pressure drop. The momentum pressure head for the liquid is less than for the mixture of vapor and liquid. Should the analysis of excessive flow rates be attempted, the calculated increment for the pressure drop will be found to be high. The program was not written to accurately calculate the thermal properties of the fluid when the pressures deviate widely from the inlet conditions. Two tests are provided in the program to avoid meaningless analysis. A particular case is terminated when the calculated pressure is less than zero, or if the section length is negative. Print outs are provided to give the reason for early case termination.

The basic assumptions made for these programs include the following:

1. Steady state conditions have been reached.

2. No heat is transferred from the outer edges of the fins. Corrections can be made for this item in program 5-2 if this feature is applicable and if the user wishes to expend the effort to do so. Normally the accuracy of the problem does not warrant such refinement.

3. No heat is transferred in the direction parallel to the duct. The temperature gradient in this direction is normally small enough that its effect does not materially degrade the predicted performance.

4. The environment remains constant along a fin and throughout the length of the duct.

5. The heat transfer properties of the duct and fin materials are not affected by temperature or position in the system.

6. The duct wall temperature is assumed equal to the temperature of the vapor.

7. The fin equivalent length remains constant along the duct and in Program 5-1 is calculated at the fluid inlet temperature.

8. The fluid enters the duct at its saturation temperature and pressure. However, the weight percentage of vapor is an input variable which depends upon the desired problem conditions.

NOMENCLATURE

Equations	Computer Program	Definition
A_d	AD	Duct cross sectional area for fluid flow, sq ft/duct
A	A(I), AA(I), AAA(I)	Curve fit equation constants [see Eq. (128), Ref. 3]
A_e		An element of condenser area, sq-ft
α_a	ALPHAA	Absorptivity of surface facing sun, nondimensional
α_b	ALPHAB	Absorptivity of surface away from sun, nondimensional
A_p	AS	Plan form area exchanging heat with the environment. (Heat may be exchanged from both sides of the extended surface), sq ft
B	B(I), BB(I), BBB(I)	Curve fit equation constants [see Eq. (128), Ref. 3]
N	CAPN	Number of ducts in heat exchanger
χ	CHI	Pressure drop function [see Eq.(114), Ref. 3], nondimensional
C_χ	CHIC1	Pressure drop constant [see Eq.(116), Ref. 3]
C	C(I), CC(I), CCC(I)	Curve fit equation constants [see Eq.(128), Ref. 3]
$K_{o,4}$	CKO, CK1, CK4	Heat transfer constants, [see Eqs. (2.15) to (2.17)
	CM(I)	Subscripted constant in Runge-Kutta-Gill integration routine
$(C_p)_g$	CPG	Specific heat of vapor, Btu/lb R
$(C_p)_L$	CPL	Specific heat of liquid, Btu/lb R
C_1	C1	Radiation constant, $\sigma(\epsilon_a + \epsilon_b)$ Btu/ft^2·hr R^4

Equations	Computer Program	Definition
$C_1(L)$	C1(L)	Radiative constant, C_1, for fin (L), Btu/hr sq ft R^4
$C_{1d}(I)$	C1D(I)	Radiative constant, C_1, for duct section (I), Btu/hr sq ft R^4
C_2	C2	Radiative constant, heat received from environment by both surfaces of a unit of fin area, Btu/hr sq ft
$C_{2d}(I)$	C2D(I)	Radiative constant C_2 for duct section (I), Btu/hr sq ft
$C_2(L)$	C2(L)	Radiative constant C_2 for fin (L) (heat to both surfaces), Btu/hr sq ft
C_3	C3	Environmental parameter, $C_2/C_1(T^*)^4$, nondimensional
δ_h	DELTAH	Thickness of root or attachment end of extended surface, ft
dw_L	DELWL	Weight of liquid changing phase in each section, lb/sec
δ_r	DELTAR	Ratio of end to root thickness of fin
D_i	DI	Duct inside diameter (or effective diameter), ft
D	D(I)	R_L curve fit constant [see Eq.(129), Ref 3]
D_o	DO	Tube outside diameter, ft
C_{DP}	DPC1	A constant [see Eq.(99), Ref. 3]
	DPM	Change in momentum pressure from entrance to exit of duct (+ if pressure rise), lb/sq ft
C_{D1}	DPMDW1	A constant [see Eq.(141), Ref. 3]
C_{D2}	DPMDW2	A constant [see Eq.(140), Ref. 3]
C_{D3}	DPMDW3	A constant [see Eq.(142), Ref. 3]
C_{D4}	DPMDW4	A constant [see Eq.(144), Ref.3]

Equations	Computer Program	Definition
C_{D5}	DPMDW5	A constant [see Eq.(145), Ref. 3]
dP_m/dw_L	DPMDWX	Pressure change in the duct due to momentum change in the fluids, lb-sec^2/lb-ft^2
	DPSUM	Accumulated sum of pressure change, lb/sq ft
dP_f/dx	DPXF	Friction pressure drop per foot of duct length, lb/ft^3
dL_w	DX	Differential length of duct, ft
DZ0	DZ0	$(dZ/d\omega)_1$ for a previous attempt at convergence where heat transfer was low
DZW	DZW	$(dZ/d\omega)_1$ for a previous attempt at convergence where heat transfer was high
$(dZ/d\omega)_1$	DZ1	Initial value of $(dZ/d\omega)$ to start integration routine, nondimensional
$\frac{d^2Z}{d\omega^2}$	D2Z	Function statement, nondimensional
Ω_c	EFC1	Flat plate convective effectiveness, nondimensional
E	E(I)	R_L curve fit constant [see Eq.(129), Ref. 3]
	EKEND	Fluid kinetic energy at duct exit, Btu/lb
E_{ks}	EKS	Fluid kinetic energy at duct entrance, Btu/lb
L_c	ELC	Duct width for convective heat transfer, ft
L_e	ELE	Equivalent length of a fin, ft
$L_e(L)$	ELE(L)	Equivalent length for fin (L), ft
L_h	ELH	Actual extended surface width, ft.
L_w	ELW	Duct length, ft
ϵ_a	EMA	Hemispherical emissivity of extended surface facing sun, nondimensional
ϵ_b	EMB	Hemispherical emissivity of extended surface away from sun, nondimensional

Equations	Computer Program	Definition
ϵ_x	EMX	Hemispherical emissivity of external surface x, nondimensional
N	ENT	Number of ducts in heat exchanger
ϵ_a	EPSA	Emissivity of extended surface facing sun, nondimensional
ϵ_b	EPSB	Emissivity of extended surface away from sun, nondimensional
ϵ_m	EPSM	Emissivity of body "m", nondimensional
ϵ_x	EPSX	Emissivity of external body, "x", nondimensional
F_a	FA	Radiative form factor between exchanger and body, "m", for surface facing sun, nondimensional
F_{ah}	FAH	Environmental convective parameter, $[h_a T_{aa} + h_b T_{ab}) L_h^2/k\delta_h T]$, nondimensional
F_{ax}	FAX	Radiative form factor between the heat exchanger surface facing the sun and a second surface near the exchanger, nondimensional
F_b	FB	Radiative form factor between exchanger and body "m" for surface away from sun, nondimensional
F_{bx}	FBX	Radiative form factor between the exchanger surface away from sun and a second surface near the exchanger, nondimensional
F_e	FE	Variable used in Newton's iteration procedure
F_h	FH	Extended surface convective parameter, $[(h_a + h_b) L_h^2/k\delta_h]$, nondimensional
h_{fg}	FHH	Latent heat of fluid, Btu/lb
F	F(I)	R_L curve fit constant [see Eq.(129), Ref. 3]
L_h	FINLH	Extended surface length of section, ft
δ_c	FINTC	Thickness of extended surface at cold end, ft

Equations	Computer Program	Definition
δ_h	FINTH	Thickness of extended surface at root edge, ft
N_s	FMESH	Number of subsections in which the duct length is divided for calculation purposes, nondimensional
μ_g	FMUG	Viscosity of vapor, lb/sec-ft
μ_L	FMUL	Viscosity of liquid, lb/sec-ft
k	FNK	Thermal conductivity of fin material, Btu/ft-hr°R
	FO(I)	Subscripted integration term
f	F2	Fanning friction factor, nondimensional
g	G	Units conversion factor, 32.17, ft/sec^2
gD_i	GDI	Product of g and tube inside diameter, ft^2/sec^2
$G_{d1,3}$	GD1,...GD3	Heat exchange constants for duct
gJ	GJ	Product of gravity and the mechanical equivalent of heat, 32.17 × 778 ft^2-lb/Btu-sec^2
$G_2(L)$	G2(L)	Subscripted constants
$G_3(L)$	G3(L)	Subscripted constants
h_a	HA	Convective heat transfer coefficient on the side facing the sun (if applicable) Btu/hr sq ft R
$h_a(L)$	HA(L)	Convective heat transfer coefficient to the environment for side "a" of fin (L), Btu/hr sq ft R
h_{at}	HAT	Sum of convective terms, $(h_a T_{aa} + h_b T_{ab})$, Btu/hr sq ft
h_b	HB	Convective heat transfer coefficient on the side away from the sun (if applicable), Btu/hr sq ft R

Equations	Computer Program	Definition
$h_b(L)$	HB(L)	Convective heat transfer coefficient to the environment from side"b" of fin (L), Btu/hr sq ft R
$h_d(I)$	HD(I)	Convective heat transfer coefficient to environment from duct section (I), Btu/hr sq ft R
h_L	HG	Enthalpy of liquid, Btu/lb
h_g	HL	Enthalpy of vapor, Btu/lb
h_t	HT	Sum of convective heat transfer coefficients, $(h_a + h_b)$, Btu/hr sq ft R
	ISO	Switch to signal a zero condition has been encountered
	ISW	Switch to signal a wilt condition has been encountered
	ITER	The number of attempts for a starting value of DZ/dω
ω	OMEGA	Ratio, L/L_h where L represents distance that the heat has traveled along the fin and L_h represents the total length, nondimensional
	P	Absolute fluid pressure, lb/sq ft
p	PERIM	Duct internal perimeter, ft
φ	PHI	Function [see Eq.(113), Ref. 3]
	PMEND	Fluid momentum pressure of duct exit, lb/sq ft
P_{ms}	PMS	Fluid momentum pressure at duct entrance, lb/sq ft
P^*	PSTAR	Static saturation pressure at duct inlet, lb/ft^2
X^*	QALSTR	Quality of fluid entering duct, weight fraction vapor, nondimensional

Equations	Computer Program	Definition
q	Q	Heat exchanged with environment, Btu/hr per duct
q_d	QDPR	Heat transfer from duct per foot of length, Btu/hr-ft
q	QS	Heat transfer to the environment from a unit of duct length, Btu/sec
q_s	QSUM	System heat exchanged with environment, Btu/hr
R	R	Gas constant, 1544/M, ft-lb/lb-mol
R_{eg}	REGP	Pseudo Reynolds number for vapor in duct, nondimensional
R_e		Reynolds number for a fluid flowing in a duct, nondimensional
R_{eL}	RELP	Pseudo Reynolds number for liquid in the duct, nondimensional
R_g	RGP	Fraction of the duct filled with vapor at the section midpoint, nondimensional
R_L	RLP	Fraction of the duct filled with liquid at the section midpoint, nondimensional
ρ		Fluid density, lb/ft^3
	RHOEND	Fluid density at duct exit, lb/cu ft
ρ_{fs}	RHOFS	Fluid density at duct entrance, lb/cu ft
ρ_g	RHOG	Density of vapor fraction, lb/ft^3
ρ_L	RHOL	Density of condensed liquid, lb/ft^3
ρ_f	RHOFM	Density of fin material, lb/ft^3
ρ_m	RHOM	Reflectivity of environmental surface, nondimensional
ρ_d	RHOTM	Density of tube material, lb/ft^3
ρ_x	RHOX	Reflectivity of second surface, x, nondimensional

Equations	Computer Program	Definition
	RLAFEG	Subroutine used in pressure drop calculations
S_c	SC	Solar heat, Btu/hr sq ft
$S_c(I)$	SC(I)	Peripheral duct length for convective heat transfer from section (I), ft
$S_r(I)$	SR(I)	Effective peripheral duct length for radiative heat transfer from section (I), ft
T	T	Absolute static temperature of vapor and fin root (taken equal), R
T_{aa}	TAA	Ambient fluid temperature on side "a", R
$T_{aa}(L)$	TAA(L)	Ambient environmental temperature for side "a" of fin (L), R
T_{ab}	TAB	Ambient fluid temperature of side "b", R
$T_{ab}(L)$	TAB(L)	Ambient environmental temperature for side "b" of fin (L), R
$T_a(I)$	TA(I)	Ambient environmental temperature for duct section (I), R
T_e	TE	Effective environmental temperature, [see Eqs.(1.14) and (2.20)], R
θ_m	THETAM	Angle between sun's rays and normal to body "m" surface, degrees
θ_p	THETAP	Angle between sun's rays and normal to fin surface, degrees
θ_x	THETAX	Angle between sun's rays and normal to second surface, degrees
T_m	TM	Surface temperature of body "m", R
T^*	TSTAR	Temperature of fluid (must be saturated) and also tube wall at inlet, R

Equations	Computer Program	Definition
T_x	TX	Surface temperature of body "x", R
	T(2)	Existing value of ω, nondimensional
$d\omega$	T(3)	Increment of ω used for calculations, nondimensional
Z	T(4)	Value of T/T*, nondimensional
$dZ/d\omega$	T(5)	$dZ/d\omega$, nondimensional
U	U	Vapor velocity in duct, ft/sec
	UFEND	Fluid velocity at duct exit, ft/sec
U_{fs}	UFS	Fluid velocity at duct entrance, ft/sec
	UP2	Pseudo velocity of vapor in duct (as if vapor occupied entire volume), ft/sec
U^*	UZERO	Fluid velocity at duct entrance, (equal velocities assumed), ft/sec
u^2	U2	Square of the vapor velocity, ft^2/sec^2
V	V	Liquid velocity in duct, ft/sec
v_f	VF	Specific volume of the liquid, ft^3/lb
v_g	VG	Specific volume of the vapor, ft^3/lb
v_{fg}	VFG	Specific volume increase during evaporation, ft^3/lb
V_f		Fluid velocity in a duct, ft/sec
V^2	V2	Square of the liquid velocity, ft^2/sec^2
w	W	Weight rate in one duct, lb/sec
	WALTH	Tube wall thickness, ft
	WD	Weight of a tube, lb
$\dot{w}$	WDOT	Total weight rate of flow, vapor and liquid, lb/hr
$\dot{w}_d$	WDOTD	Weight flow of fluid in a duct, lb/hr-tube

Equations	Computer Program	Definition
W_d^1	WDPR	Weight of the duct per foot of length, lbs/ft
W_e	WE	Weight of extended surface, lb
	WILT	Value of $(dZ/d\omega)_1$ used for the previous iteration, nondimensional
w_g	WG	Weight flow rate of vapor in duct, lb/sec
w_L	WL	Weight flow rate of the liquid in duct, lb/sec
W_{Lt}	WLT	Weight of the liquid trapped in the condenser, lb
W_q	WQ	Dry condenser weight per unit of heat transfer, lb-hr/Btu
W_t	WT	Total weight of condenser (neglecting fluid), lb
M	WTM	Molecular weight of fluid, lb/mol
y		Heat transfer rate at fin root temperature, Btu/hr sq ft
Y_L		Lockhart-Martinelle Correlation factor
Z	Z	Correction factor, $P/\rho_g RT$, nondimensional also used as a dimensionless ratio, i.e., the temperature in a fin at a given section divided by the hot end temperature
ζ_p	ZETAP ZZ	Profile number, $C_1 T^3 L_h^2/k\delta_h$, for rectangular plan extended surface, nondimensional

SUBSCRIPTS

a	Surface facing the sun (if applicable)
b	Surface in shade (if applicable)
(I)	Duct section "I" or φ curve fit for section "I"
(L)	Fin "L"

1	Denotes entrance to duct section (if applicable)
2	Denotes exit from duct section (if applicable)

PROGRAM 5-1 DESCRIPTION

This program is adapted to systems having the geometry shown in Fig. 1. Much of the work presented is common to the two programs and the overlapping portions will not be repeated.

The heat transfer from an element of fin surface depicted in Fig. 2 in a radiative and convective environment can be written as

$$dq = [C_1 T^4 - C_2 + h_a(T - T_{aa}) + h_b(T - T_{ab})]\, dA_p . \tag{1.1}$$

The radiative constants C_1 and C_2 are

$$C_1 = (\epsilon_a + \epsilon_b)\sigma = (\epsilon_a + \epsilon_b)0.1713\text{x}10^{-8} \tag{1.2}$$

[Ref. 3 ,Eq. 2]*

and

$$\begin{aligned} C_2 = {} & S_c(\alpha_a \cos\theta_p + F_a\alpha_a\rho_m \cos\theta_m + F_{ax}\alpha_a\rho_x \cos\theta_x + F_b\alpha_b\rho_m \cos\theta_m \\ & + F_{bx}\alpha_b\rho_x \cos\theta_x) + 0.1713\text{x}10^{-8}\Big[(F_a\epsilon_a + F_b\epsilon_b)\epsilon_m T_m{}^4 \\ & + (F_{ax}\epsilon_x + F_b\epsilon_b)\epsilon_x T_x{}^4\Big] + 0.01(\epsilon_a + \epsilon_b). \end{aligned} \tag{1.3}$$

[Ref. 3, Eq. 3]

The heat transfer from an element of fin can be written as

$$dq = yL_e\, dL = \frac{-k\delta_h T}{L_h}\left(\frac{dZ}{d\omega}\right)_1 dL_w \tag{1.4}$$

---

*This denotes the source of the equation.

where

$$y = C_1 T^4 - C_2 + T h_t - h_{at} \tag{1.5}$$

$$h_t = h_a + h_b \tag{1.6}$$

and

$$h_{at} = h_a T_{aa} + h_b T_{ab} \; . \tag{1.7}$$

Thus y is the heat exchanged per hour per unit area at the wall temperature.

Rearranging Eq.(1.4) and combining with (1.5)

$$L_e = \frac{-L_h \left(\frac{dZ}{d\omega}\right)_1}{C_p(1-C_3) + F_h - F_{ah}} \tag{1.8}$$

[Ref. 1, Eq. (1.8)]

The value of $(dZ/d\omega)_1$ is obtained at the inlet vapor temperature, T*, by the numerical integration procedures described in Ref. 2, Eqs. (4) through (23).

The heat transfer from an element of tube can be obtained by adding the amounts resulting from both radiation and convection. However, in this program each mode of heat transfer is calculated differently. As explained in Ref. 1, the heat transferred by radiation from a fin and tube system can be readily evaluated with excellent accuracy using the projected area of the tube. In this program the heat transferred by convection is assumed to take place from the exposed area of the tube. Using these areas, the heat exchange is

$$dq_d = [D_o(C_1 T^4 - C_2) + L_c(h_t T + h_{at})] \, dL_w \tag{1.9}$$

[Ref. 1, Eq. (1.9)]

where

$$L_c = \frac{\pi D_o}{2} - \delta_h \ . \tag{1.10}$$

The total heat from the surface to the environment is obtained by combining equations (1.4) and (1.9). For the element

$$dq = 3600 \ \bar{q} \ dL_w \tag{1.11}$$

for the system total

$$q_s = 3600N \sum_{L_w=0}^{L_w} \bar{q} \ dL_w \tag{1.12}$$

where $\bar{q}$ represents the heat exchanged with the environment per second per foot of tube length or

$$\bar{q} = [2yL_e + D_o \ (C_1 T^4 - C_2) + L_c (h_t T - h_{at})] \div 3600. \tag{1.13}$$

The environmental temperature (defined as the one the fluid would reach if the duct were infinitely long) was calculated from Eq. (1.13) by putting $\bar{q} = 0$ and $T_e = T_w$. The value of T_e was obtained using Newton's method in which

$$T_e = T_e' - F_e \Big/ \frac{dF_e}{dT_e} \tag{1.14}$$

where

$$F_e = (C_1 T_e^4 - C_2)(2L_e + D_o) + (h_t T_e - h_{at})(2L_e + L_c) \tag{1.15}$$

and

$$\frac{dF_e}{dT_e} = 4C_1 T_e^{\ 3}(2L_e + D_o) + h_t (2L_e + L_c) \tag{1.16}$$

T^* was used as the first approximation for T_e and T_e was accepted when

$$F_e \leqq 0.001. \tag{1.17}$$

When convection is absent

$$h_t = 0, \tag{1.18}$$

$$y = C_1 T_e^4 - C_2, \tag{1.19}$$

$$q_d = D_o (C_1 T_e^4 - C_2), \tag{1.20}$$

and with these substitutions in Eq. (1.13) and rearrangement

$$T_e = \left(\frac{C_2}{C_1} \right)^{\frac{1}{4}}. \tag{1.21}$$

The mixed fluid properties at the tube inlet are calculated assuming the two fluids are traveling at the same velocity. From the continuity equation for each constituent

$$A_L = w_L \,/\, \rho_L V \tag{1.22}$$

$$A_g = w_g \,/\, \rho_{gs} U \tag{1.23}$$

For equal velocities

$$U_{fs} = U = V \tag{1.24}$$

The duct area is equal to the sum of the areas occupied by the two fractions or

$$A_L + A_g = A_d \tag{1.25}$$

Combining Eqs. (1.23) through (1.25) and rearranging the mixed fluid velocity is

$$U_{fs} = \frac{1}{A_d}\left(\frac{w_L}{\rho_L} + \frac{w_g}{\rho_{gs}}\right) \tag{1.26}$$

The fluid momentum pressure (velocity X mass/sec) is

$$P_{ms} = \frac{1}{gA_d}\left(\rho_L A_L V^2 + \rho_{gs} A_g U^2\right) \tag{1.27}$$

The total flow is the sum for the two fractions or

$$w = w_L + w_g \tag{1.28}$$

Combining Eqs.(1.22), (1.23), (1.24), (1.27) and (1.28)

$$P_{ms} = \frac{w\,U_{fs}}{g\,A_d} \tag{1.29}$$

The kinetic energy per pound of fluid at duct entrance is

$$E_{ks} = U_{fs}^{\;2} / 2gJ\ . \tag{1.30}$$

A similar set of equations is applicable to the fluid leaving the duct. No assumptions need be made for velocity distribution since w_L = zero in an evaporator and w_g = zero in a condenser.

In these programs the size and shape of the system is specified except for the length of tubes needed to condense the vapor or evaporate the liquid. The length of tube and pressure drop along it are determined simultaneously by calculating the pressure drop over an increment of tube length, and then performing a step-by-step numerical integration down the length of

PROGRAM 5-2 DESCRIPTION

This program is set up to handle a variety of duct and fin configurations as illustrated by Fig. 4. In order to make it flexible the number of extended surfaces attached to the duct and the divisions of the duct circumference are specified by the input data. The heat transfer to the extended surface is calculated for each surface from its equivalent length. The heat transfer from the duct is obtained by adding the radiative and convective heat transfer from each of the sections.

When the radiative heat transfer to the environment from a given extended surface is independent of the other extended surfaces, the programs in Ref. 2 can be used to calculate the equivalent length for the surface. Unfortunately, when the extended surfaces are oriented in such a way that they can "see" each other, the heat transfer by radiation to the environment is restricted and no known programs are available for calculating the equivalent length. At present the user will have to approximate the reduction in heat transfer and adjust the values of L_e accordingly. The approximations will be sufficiently accurate if the interfering surfaces are insulated, or if the ambient fluid is opaque to radiation.

The cross sectional flow area for the duct can be calculated by the program when the duct is circular. If not, the area and duct perimeter must be included in the input data. The effective internal diameter used to compute pressure drop for a non-circular duct is

$$D_i = \frac{4A_d}{p} . \qquad (2.1)$$

For circular ducts

$$A_d = \frac{\pi D_i^2}{4} \quad . \tag{2.2}$$

and

$$p = \pi D_i \quad . \tag{2.3}$$

To account for the two modes of heat transfer with the environment, the calculations for a section of duct circumference are divided into two parts, convection and radiation. The division is necessary because of the use of projected areas, if applicable, for calculating radiative heat transfer. Also it is assumed that the duct itself might be of a complicated configuration requiring several sections to adequately represent the heat transfer. For an element of any section, the heat transfer can be written as

$$dq(I) = \left\{S_r(I) \left[C_{1d}(I)\ T^4 - C_{2d}(I)\right] + S_c(I)\ h_d(I) \left[T - T_a(I)\right]\right\} dL. \tag{2.4}$$

The effective section lengths $S_r(I)$ and $S_c(I)$ are thus chosen independently. In some cases, for example a duct without fins, equal values for $S_r(I)$ and $S_c(I)$ should be specified. The total heat transfer from an element of duct circumference is the sum of the amount from all sections, or

$$dq_d = (G_{d1}\ T^4 + G_{d2}\ T - G_{d3})dL \tag{2.5}$$

where

$$G_{d1} = \sum_{I=1}^{n} S_r(I)\ C_{1d}(I) \tag{2.6}$$

$$G_{d2} = \sum_{I=1}^{n} S_c(I)\ h_d(I) \tag{2.7}$$

and

$$G_{d3} = \sum_{I=1}^{n} \left[S_r(I)\ C_{2d}(I) + S_c(I)\ h_d(I)\ T_a(I) \right] . \tag{2.8}$$

For an extended surface the heat transfer is

$$dq(L) = \left\{ C_1(L)\ T^{4} - C_2(L) + T \left[h_a(L) + h_b(L) \right] - \left[h_a(L)\ T_{aa}(L) + \right.\right.$$
$$\left.\left. + h_b(L) T_{aa}(L) \right] \right\} L_e(L) dL. \tag{2.9}$$

setting

$$G_2(L) = h_a(L) + h_b(L) \tag{2.10}$$

and

$$G_3(L) = h_a(L)\ T_{aa}(L) + h_b(L)\ T_{ab}(L) + C_2(L), \tag{2.11}$$

$$dq(L) = \left[C_1(L)\ T^{4} + G_2(L)\ T - G_3(L) \right] L_e(L)\ dL. \tag{2.12}$$

The heat from an element of duct length can be obtained by adding the heat from the extended surfaces and the duct or

$$dq = 3600\ \bar{q}\ dL_W \tag{2.13}$$

Where

$$\bar{q} = [K_o + K_1 T + K_4 T^{4}] \tag{2.14}$$

$$K_o = - \left(G_{d3} + \sum_{L=1}^{n'} G_3(L)\, L_e(L) \right) \tag{2.15}$$

$$K_1 = G_{d2} + \sum_{L=1}^{n'} \left[G_2(L) \; L_e(L) \right] \tag{2.16}$$

$$K_4 = G_{d1} + \sum_{L=1}^{n'} \left[G_1(L) \, L_e(L) \right] \tag{2.17}$$

and

n' = number of fins attached to a duct.

Equation (2.14) is used with Newton's method for establishing the effective environmental temperature. Setting, $\bar{q} = 0$ and $T_e = T$

$$F_e = K_0 + K_1 T_e + K_4 T_e^4 \tag{2.18}$$

$$dF_e \,/\, dT_e = K_1 + 4K_4 T_e^3 \tag{2.19}$$

and

$$T_e = T_e' - F_e \bigg/ \frac{dF_e}{dT_e} \quad . \tag{2.20}$$

The inlet fluid temperatures T^* is used as the first approximation for T_e'. The value of T_e is accepted when

$$F_e \leq .001 \; . \tag{2.21}$$

CONCLUSIONS AND RECOMMENDATIONS

These programs can be used to solve a myriad of evaporator and condenser problems. While they have been specifically designed for problems where the heat exchange with the environment is by the combination of convection and radiation, they can be used where the transfer is restricted to one or the other. Problems involving only convection environments are also solvable by conventional approaches and such a program would be a little bit more economical with machine time.

The rigorous mathematical treatment of the combined effects of radiation and convection heat exchange systems has been avoided in the past because of the difficulties in solving the nonlinear differential equations. These difficulties are made acute by the large number of variables which influence the exchanger performance. Radiative exchange problems have been greatly simplified by the use of dimensionless parameters. Comparable studies with the combined effects of radiation and convection are sorely needed. Performance curves or charts would aid in the understanding of problems and in interpreting the results obtained for a given case. The programs presented herein combined with those of Refs. 1 and 2 should provide interested parties with the basic tools for making such a study.

Inter-radiation effects between fins which "see" each other will introduce errors which are difficult to approximate. Very little work has been done in this field.

Problems involving heating and cooling of gases and mixtures of gases can not be solved with either these programs or those of Ref. 1. The modifications required are not extensive and work in this field is recommended.

REFERENCES

1. Mackay, D. B. and Branner, W. E. "Heat Exchangers for Convective and Radiative Environments," Aerospace Technology Report #4, Rice University, August, 1968.

2. Mackay, D. B. and Branner, W. E. "Radiative and Convective Heat Transfer from Single and Multisection Extended Surfaces," Aerospace Technology Report #2, Rice University, March 1968.

3. Mackay, D. B. and Branner, W. E. "Digital Programs for Establishing Steady-State Space Condenser Performance," Aerospace Technology Report #1, Rice University, Revised April 1969.

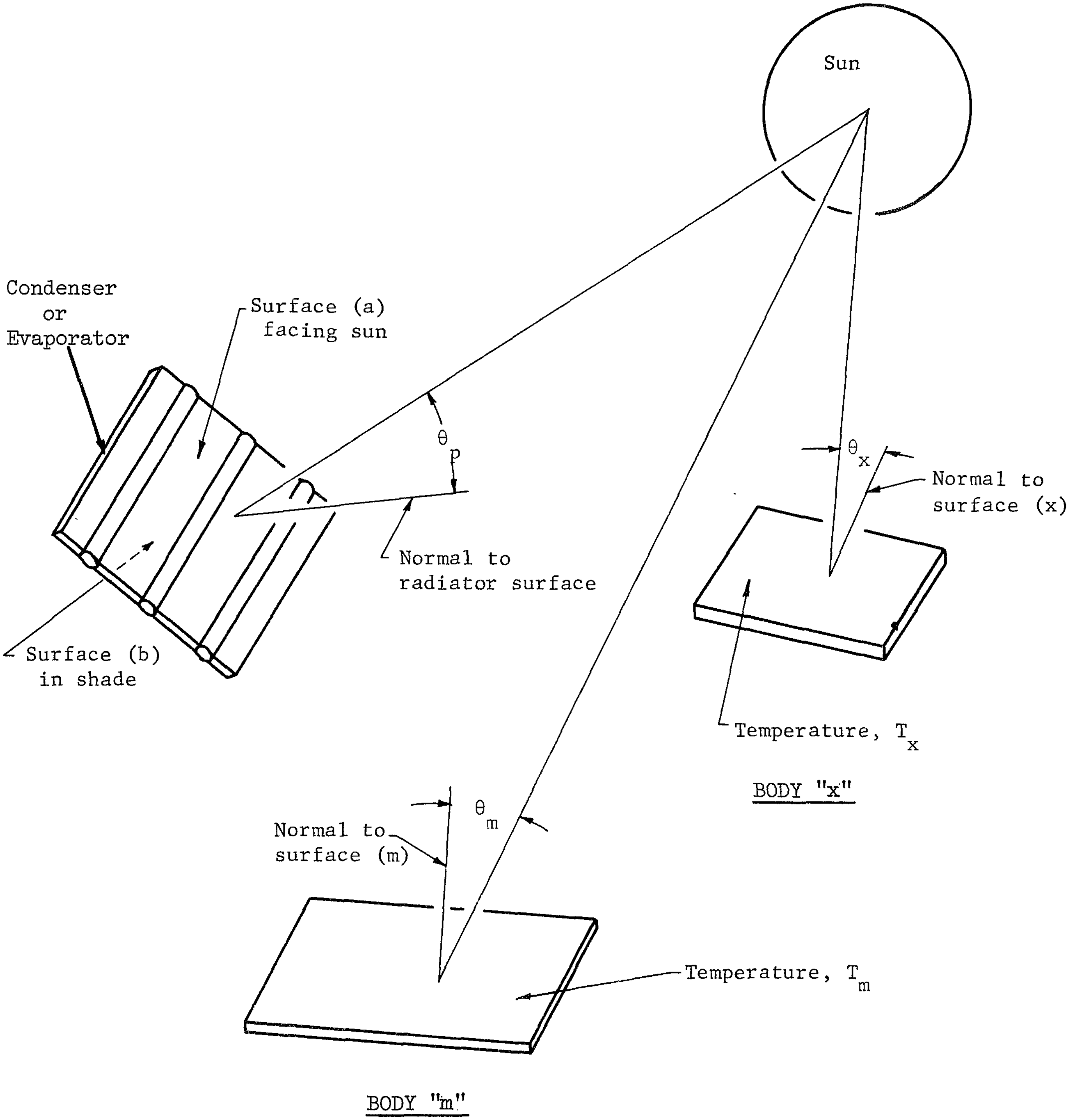


Fig. 1. Program 5.1 Radiative Environment

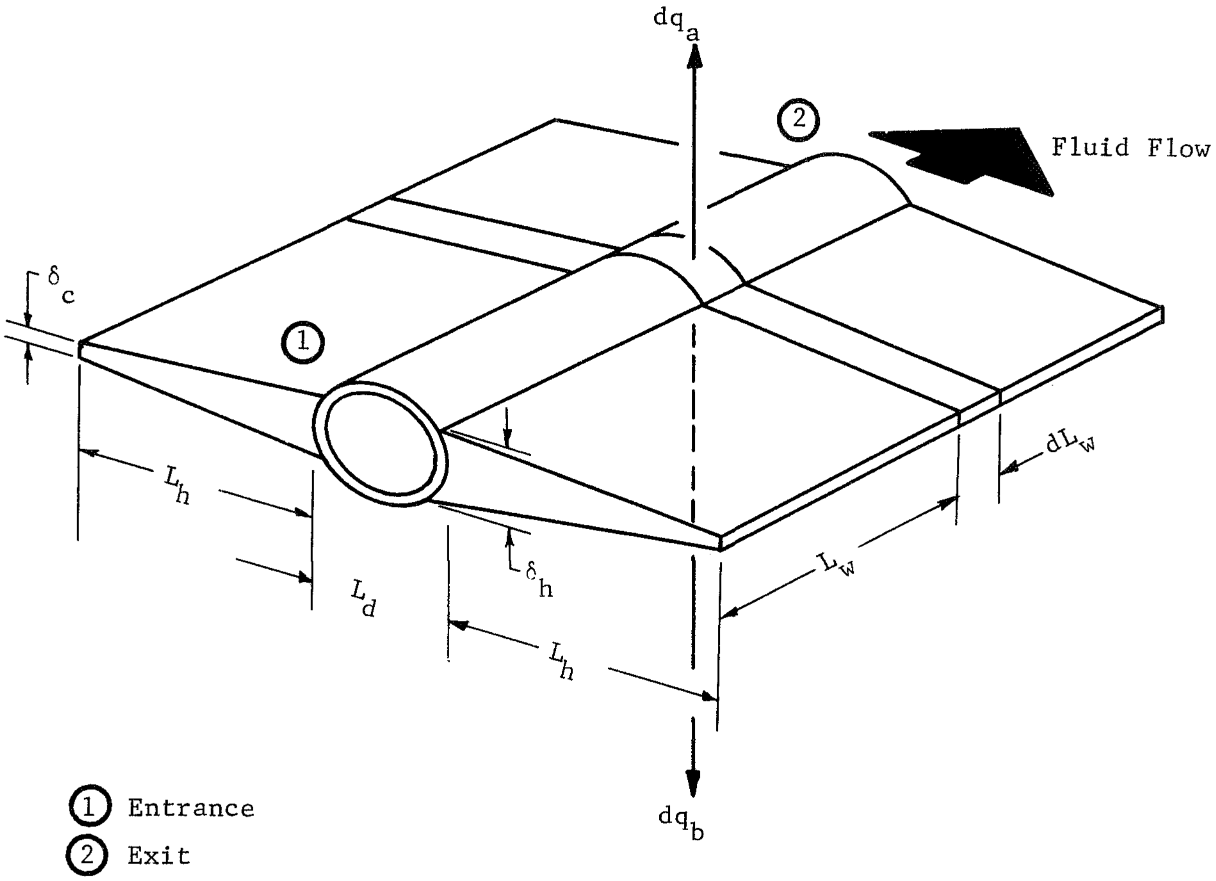


Fig. 2. Typical Configuration (Program 5.1)

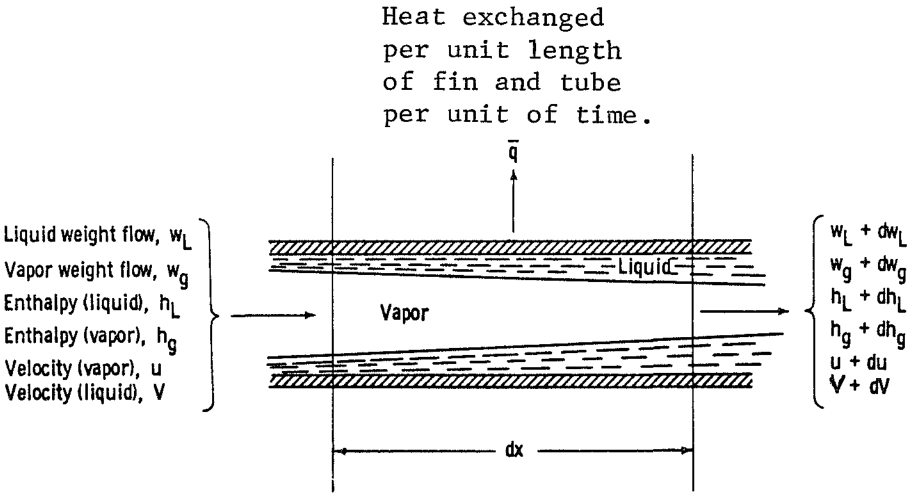


Fig. 3. Condenser Tube Two-Phase Flow Model

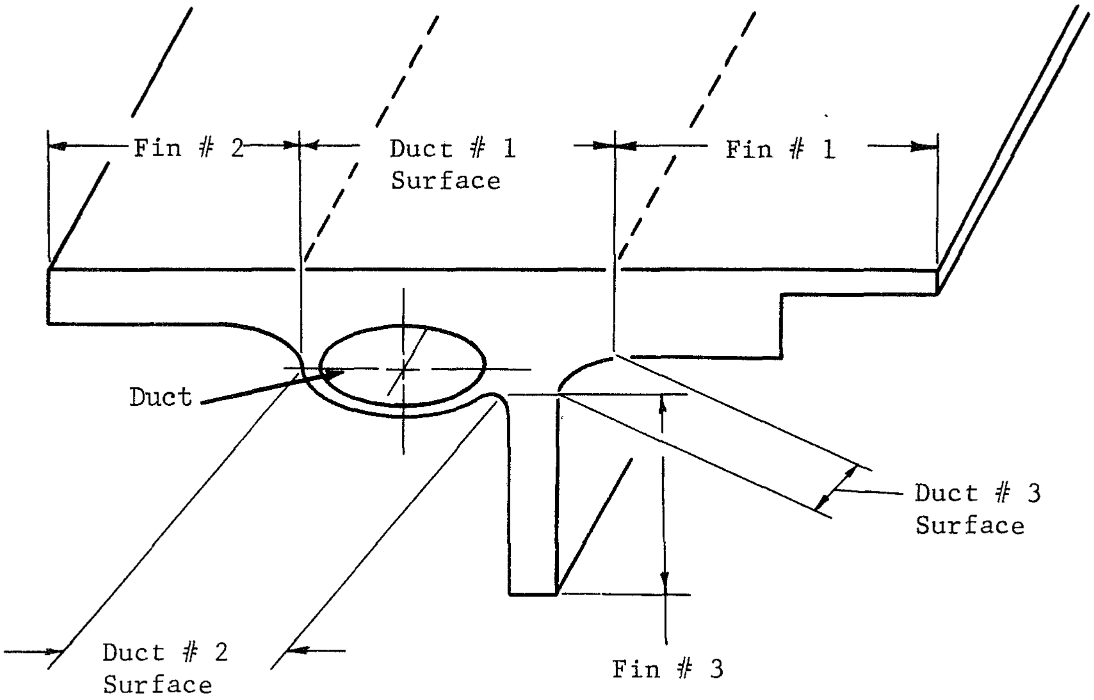


Fig. 4 Representative Configuration (Program 5.2)

APPENDIX A

PROGRAM INFORMATION

Included in this appendix are deck setups, flow diagrams, compiled listings of the main programs and subroutines, (Figures A-1 to A-5 inclusive), Information for Program Users, and Input Variables for Programs. Subroutines permanent Hollerith listings and a set of input date for sample problems are included along with program listings.

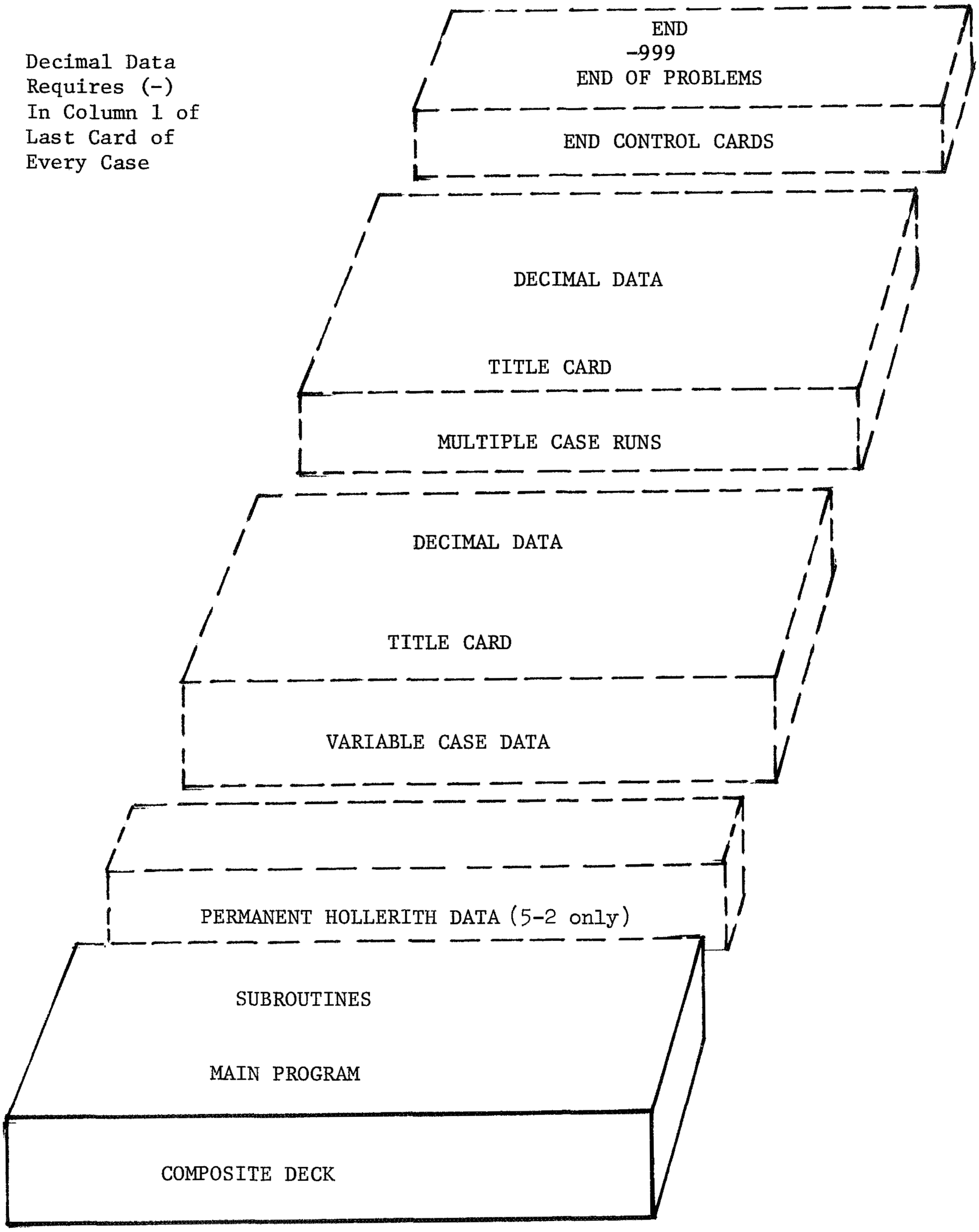


Fig. A-1. Composite Deck Setup

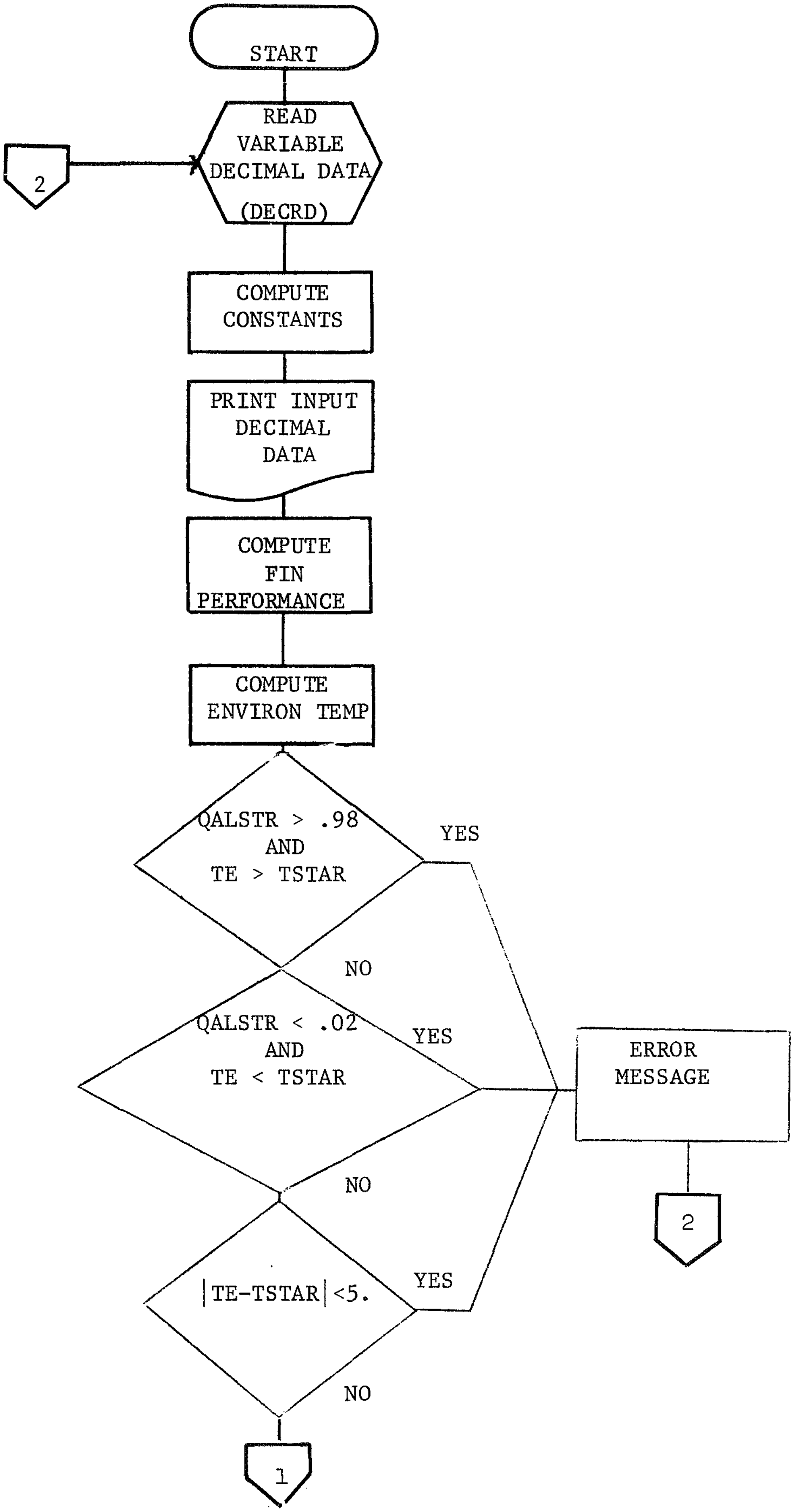


Fig. A-2. Program 5-1. Flow Diagram

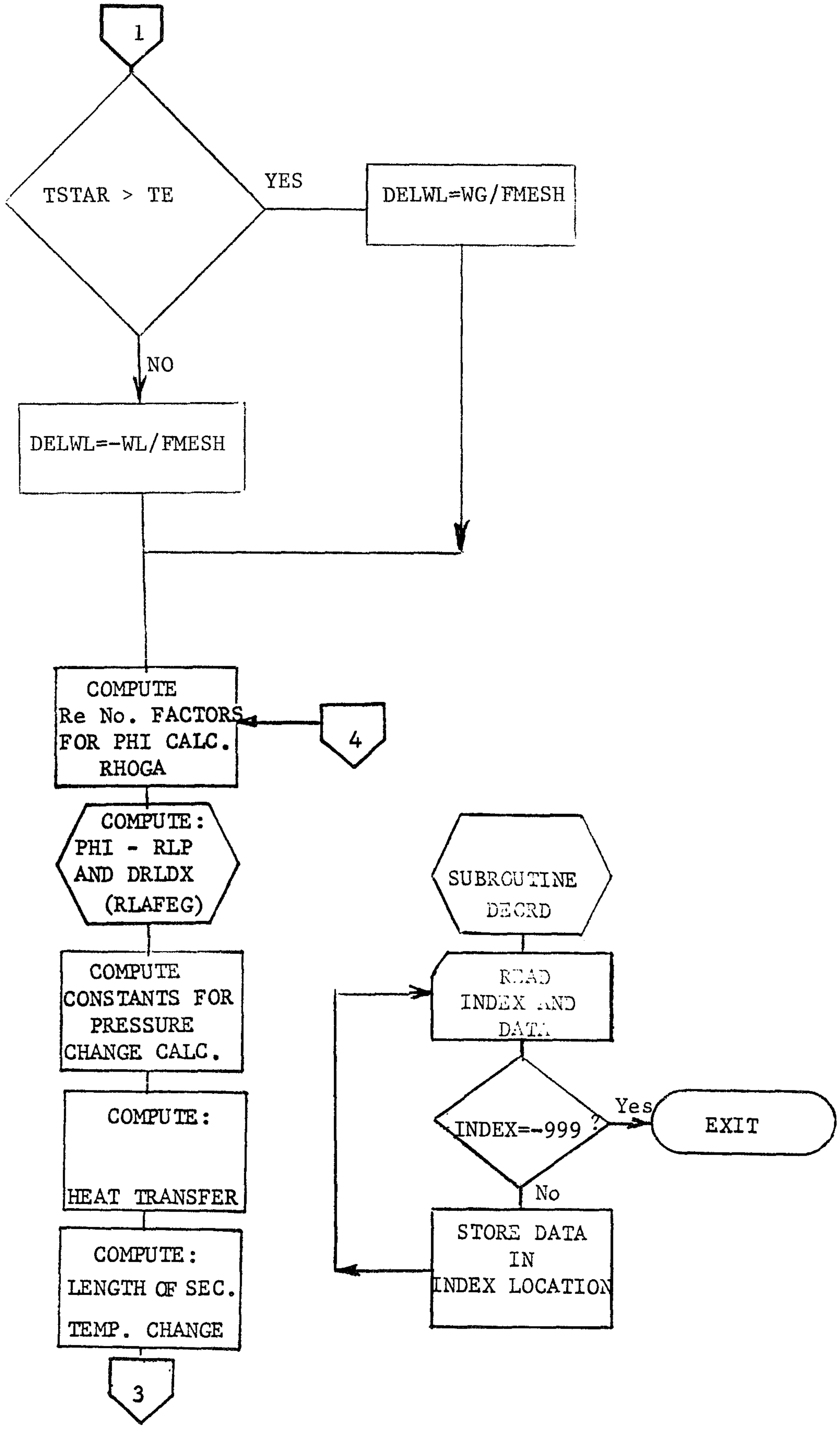


Fig. A-2. Program 5-1 Flow Diagram (cont.)

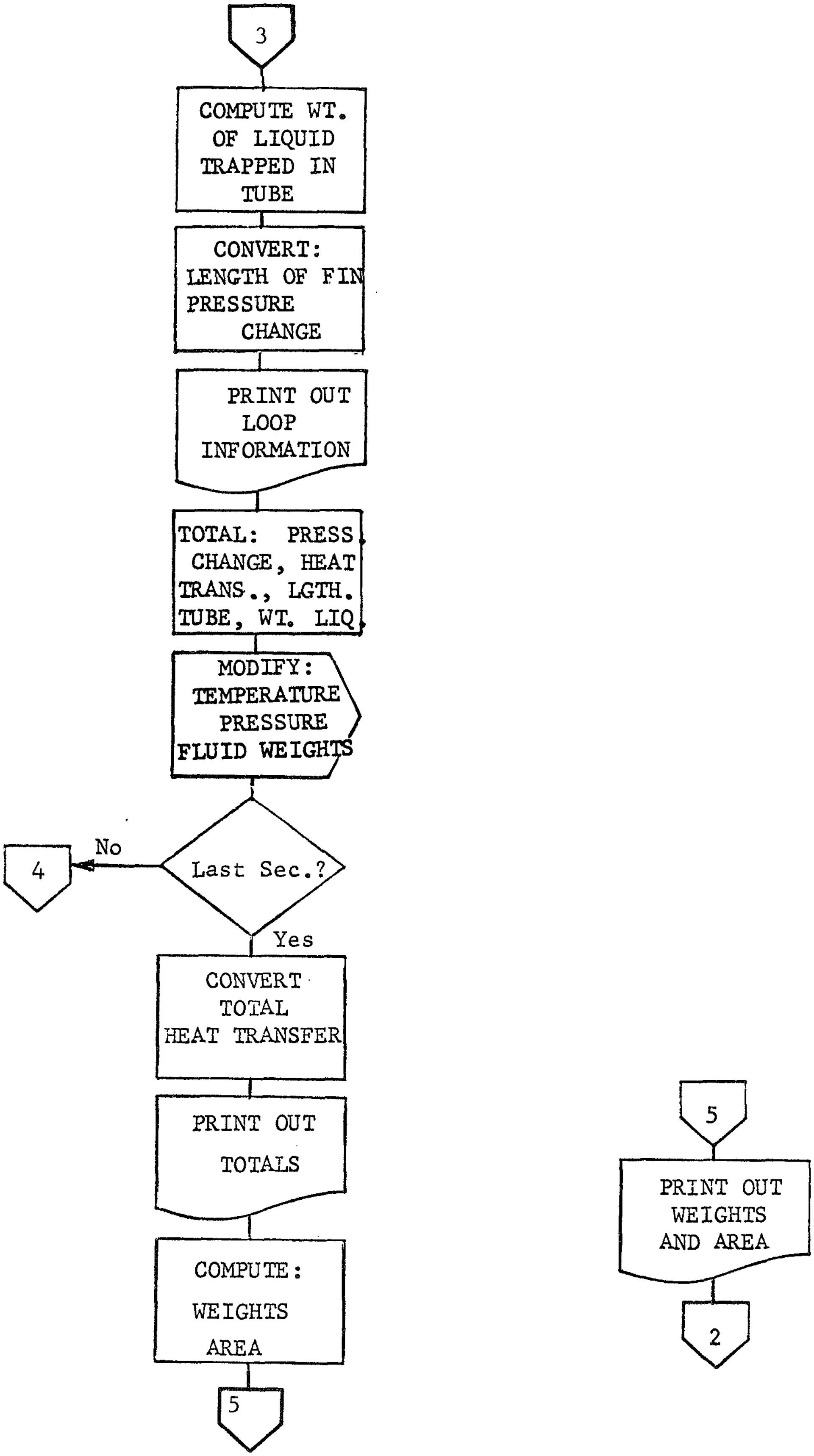


Fig. A-2. Program 5-1 Flow Diagram (cont.)

```
    PROGRAM 5-1, CONDENSER AND / OR EVAPORATOR ANALYSIS

    DIMENSION DA(50) , CARD(16)
    COMMON EMA, EMB, THETAP, FA, ALFAA, RHOM, THETAM, FAX, RHOX,
   1THETAX, FB, ALFAB, FBX, TM, EMX, TX, C1, C2, TSTAR, ELH, FNK,
   2FINTH, DELTAR, ZZ, CAPN, WDOT, QALSTR, WTM, Z, DO, DI, VF, VG,
   3FHH, HA, HB, TAA, TAB, FH, FAH, ELE, C3, PSTAR, CPL, CPG, RHOL,
   4FMUG, FMUL, THP, RHOTM

    DA(45)=1.0
    READ DATA
 10 READ 521, CARD
521 FORMAT (16A5)
    PRINT 522, CARD
522 FORMAT ("1",16A5/)
    CALL DECRD(DA)
    ENTER DATA
    FMUG=DA(8); FMUL=DA(9); TSTAR=DA(3); QALSTR=DA(10)
    WTM=DA(13); C1=DA(35); C2=DA(36); CPG=DA(37); CPL=DA(38)
    DO=DA(1); DI=DA(2); WDOT=DA(4); ELH=DA(5); FINTH=DA(6);
   VDELTAR=DA(7); FNK=DA(11); FHH=DA(12); HA=DA(14); HB=DA(15);
   VTAA=DA(16); TAB=DA(17); ALFAA=DA(18); ALFAB=DA(19);
   VEMA=DA(20); EMB=DA(21); EMX=DA(22); FA=DA(23); FAX=DA(24);
   VFB=DA(25); FBX=DA(26); RHOM=DA(27); RHOX=DA(28); ZZ=DA(29);
   VTHETAM=DA(30); THETAX=DA(31); TM=DA(32); TX=DA(33); EPSM=DA(34);
   VFMESH=DA(39); PSTAR=DA(40); INDIC=DA(41); RHOL=DA(42); FH=DA(47)
    CAPN=DA(44) ; Z=DA(45) ; RHOTM=DA(46) ; THETAP=DA(43) ; FAH=DA(48)
    CALCULATE SYSTEM CONSTANTS
    CALL C1N2(INDTC)
    ZZ=C1*TSTAR**3*ELH**2/(FNK*FINTH)
    PRINT INPUT DATA
    CALL OUT
    CALL ENTGRT
    COMPUTE ENVIRONMENTAL TEMPERATURE
    CALL TEMP(TE)
    PRINT 987, ELE, TE
987 FORMAT (6X, "CALCULATED DATA"//F15.5,5X,"EFFECTIVE LENGTH OF FIN,
   1FT."/F15.5,5X,"ENVIRONMENTAL TEMPERATURE, DEGREES R"/)
    IF (QALSTR .GT. .98 .AND. TE .GT. TSTAR) GO TO 101
    IF (QALSTR .LT. .02 .AND. TE .LT. TSTAR) GO TO 102
    IF (ABS(TSTAR-TE) .LT. 5.) GO TO 103
    SECTION CONSTANTS
    PI=3.14159
    W=WDOT/(CAPN*3600.)
    GJ=778.*32.17
    AD=PI*DI**2/4.
    GDI=32.17*DI
502 WL=(1.-QALSTR)*W
    WG=W-WL
    IF (TSTAR .GT. TE)  GO TO 1
    DELWL=-WL/FMESH ; GO TO 2
  1 DELWL=WG/FMESH
  2 P=PSTAR
    T=TSTAR
    PX=P
    FJH=778.*FHH
    DPSUM=0.0
    ELW=0.0
    QSUM=0.0
    WLTSUM=0.0
```

Fig. A-3. Program 5-1, Listing

```
      R=1544./WTM
      RHOGS=PSTAR/(TSTAR*R*Z)
      WL1=WL+DELWL/2.
      WG1=W-WL1
      UFS=(WL/RHOL+WG/RHOGS)/AD
      PRINT 49, UFS
   49 FORMAT (F15.5,5X,"MIXTURE VELOCITY AT TUBE ENTRANCE, FT/SEC"/)
      UFS2=UFS**2
      PMS=W*UFS/(32.17*AD)
      EKS=UFS2/(2.*GJ)
      MESH=FMESH
      SECTION CALCULATIONS
      DO 27 J=1,MESH
      QAL=WG1/W
      RHOGA=P/(R*T*Z)
      REGP=(4.*WG1)/(PI*DI*FMUG)
      RELP=(4.*WL1)/(PI*DI*FMUL)
      IF(REGP-2000.)28,28,29
   28 IF(RELP-2000.)30,30,31
   29 IF(RELP-2000.)32,32,33
   30 CHIC1=(FMUL*RHOGA)/(FMUG*RHOL)
      CHI=SQRT((WL1*CHIC1)/WG1)
      DCHI=W*CHI/(2.*WL1*WG1)
      F=16./REGP
      GO TO 34
   31 CHIC1=(.046*4.**.8)/(16.*(PI*DI)**.8)*(RHOGA/RHOL)*(FMUL**.2/FMUG)
      CHI=SQRT((WL1**1.8/WG1)*CHIC1)
      DCHI=(1.8*WG1+WL1)*CHI/(2.*WG1*WL1)
      F=16./REGP
      GO TO 34
   32 CHIC1=(16.*(PI*DI)**.8)/(.046*4.**.8)*(RHOGA/RHOL)*(FMUL/FMUG**.2)
      CHI=SQRT((WL1/WG1**1.8)*CHIC1)
      DCHI=((WG1+1.8*WL1)*CHI)/(2.*WG1*WL1)
      F=.046/REGP**.2
      GO TO 34
   33 CHIC1=(RHOGA/RHOL)*(FMUL/FMUG)**.2
      CHI=SQRT((WL1/WG1)**1.8*CHIC1)
      DCHI=(.9*W*CHI)/(WG1*WL1)
      F=.046/REGP**.2
   34 CALL RLAFEG (CHI,PHI,RLP,DRLDX,REGP,RELP)
      RGP=1.-RLP
      V=WL1/(RLP*AD*RHOL)
      U=WG1/(RGP*AD*RHOGA)
      V2=V**2
      U2=U**2
      UP2=(WG1/(AD*RHOGA))**2
      U2COEF=1.-((WG1*DCHI*DRLDX)/RGP)
      V2COEF=1.-((WL1*DCHI*DRLDX)/RLP)
      DPXF=-PHI**2*2.*UP2*RHOGA*F/GDI
      DPMDW1=DRLDX*DCHI
      DPMDW2=2.-((DPMDW1*WG1)/RGP)
      DPMDW3=2.-((DPMDW1*WL1)/RLP)
      DPMDW4=RHOGA*U2*RGP*DPMDW2/(32.17*WG1)
      DPMDW5=RHOL*V2*RLP*DPMDW3/(32.17*WL1)
      DPMDWX=DPMDW4-DPMDW5
      DPC1=(CPL*WL1+CPG*WG1)*T/(FJH*RHOGA)
      HT=(HA+HB)
      HAT=HA*TAA+HB*TAB
      AREA=(DO*PI-2.*DELTAH)/2.
      QS2=((C1*2.*ELE+C1*DO)*T**4+(HT*2.*ELE+HT*AREA)*T
     1+(-C2-HAT)*2.*ELE-C2*DO-HAT*AREA)/3600.
```

Fig. A-3. Program 5-1, Listing (con't)

```
      DX1=QS2+DPC1*DPXF
      DX2=FHH-V2*V2COEF/GJ+U2*U2COEF/GJ-DPC1*DPMDWX+(U2-V2)/(2.*GJ)
      DX=DX2*DELWL/DX1
      IF(DX)35,35,36
   35 PRINT 63
      GO TO 10
   36 DP= DPMDWX*DELWL+DPXF*DX
      DELT= T*DP/(FJH*RHOGA)
      WLT=RHOL*AD*RLP*DX*CAPN
      PRINT 44, J
   44 FORMAT ("0",5X,"SECTION",I10)
      PRINT 110, QAL
  110 FORMAT (F15.5,5X,"QUALITY AT MIDDLE OF SECTION")
      PRINT 111, V
  111 FORMAT (F15.5,5X,"LIQUID VELOCITY (FT./SEC.)")
      PRINT 41, U, QS2, DX, DELT, DP
   41 FORMAT (F15.5,5X,"VAPOR VELOCITY (FT./SEC.)"/F15.5,5X,
     1"QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-FT)"/
     2F15.5,5X,"DIFFERENTIAL LENGTH OF TUBE, (FT.)"/F15.5,5X,
     3"CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R"/
     4F15.5,5X,"CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)")
       T=T+DELT
       PX=P
       WL1=WL1+DELWL
       WG1=W-WL1
       DPSUM=DPSUM+DP
       P=P+DP
       IF (P .LE. 0.0) GO TO 75
       ELW=ELW+DX
       QSUM=QSUM+QS2*DX*CAPN
       WLTSUM=WLTSUM+WLT
   27  CONTINUE
       QSUM=QSUM*3600.
       PRINT 42, DPSUM, ELW, QSUM, WLTSUM
   42  FORMAT (//  F15.5,5X,"ACCUMULATED SUM OF PRESSURE CHANGE, (PSF)"/
     1F15.5,5X,"TOTAL TUBE LENGTH, FT."/F15.5,5X,
     2"A0CUMULATED SUM OF HEAT LOST, BTU/HR"/F15.5,5X,"ACCUMULATED WEIGH
     3T OF TRAPPED LIQUID, LB.")
       RHOGE=P/(T*R*Z)
       WLE=WL1-DELWL/2.
       WGE=W-WLE
       UFEND=(WLE/RHOL+WGE/RHOGE)/AD
       UFE2=UFEND**2
       PMEND=W*UFEND/(32.17*AD)
       DPM=PMS-PMEND
       EKEND=UFE2/(2.*GJ)
       WD=PI*RHOTM*ELW*(DO**2-DI**2)/4.
       WE=FINTH*ELH*RHOFM*ELW*(1.+FRTIO)/2.
       WT=CAPN*(WD+2.*WE)
       WQ=WT/QSUM
       AS=(DO+2.*ELH)*ELW*CAPN
       FINTC=FINTH*FRTIO
       PRINT 40, WD, WT, WQ, AS
   40  FORMAT (F15.5,5X,"WEIGHT OF ONE TUBE, LBS"/F15.5,5X,
     1 "TOTAL WEIGHT OF UNIT, LBS"/F15.5,5X,"WEIGHT PER UNIT OF HEAT TRA
     2NSFER, LB-HR/BTU"/F15.5,5X,"PLANFORM AREA, SQFT"/)
       PRINT  81, PMS, EKS, PMEND, EKEND, DPM
   81  FORMAT (F15.5,5X,"MOMENTUM PRESSURE AT INLET, LBS/SQFT"/
     1F15.5,5X,"KINETIC ENERGY OF FLUID AT INLET, BTU/LB          "  /
     2F15.5,5X,"MOMENTUM PRESSURE AT END, LBS/SQFT"/F15.5,5X,"KINETIC EN
     3ERGY OF FLUID AT END, BTU/LB          "/F15.5,5X,
```

Fig. A-3. Program 5-1, Listing (con't)

```
   4"CHANGE IN MOMENTUM PRESSURE, LBS/SQFT")
    GO TO 10
 75 PRINT 76
 76 FORMAT (" FLOW RATE EXCESSIVE, PRESSURE DROP GREATER THAN INLET PR
   1ESSURE")
    GO TO 10
101 PRINT 901
    GO TO 10
901 FORMAT(" TEMPERATURE IS TOO HIGH TO CONDENSE")
102 PRINT 902
902 FORMAT(" TEMPERATURE IS TOO LOW TO EVAPORATE")
    GO TO 10
103 PRINT 903
903 FORMAT(" FLUID TEMPERATURE TOO CLOSE TO ENVIRONMENTAL TEMPERATURE"
   1)
    GO TO 10
 63 FORMAT(38H FLOW RATE EXCESSIVE. GO TO NEXT CASE.)
    END



     SUBROUTINF RLAFEG (CHI,PHI,RLP,DRLOX,REGP,RELP)

     COMMON EMA, EMB, THETAP, FA, ALFAA, RHOM, THETAM, FAX, RHOX,
    1THETAX, FB, ALFAB, FBX, TM, EMX, TX, C1, C2, TSTAR, ELH, FNK,
    2FINTH, DELTAR, ZZ, CAPN, WDOT, QALSTR, WTM, Z, DO, DI, VF, VG,
    3FHH, HA, HB, TAA, TAB, FH, FAH, ELE, C3, PSTAR, CPL, CPG, RHOL,
    4FMUG, FMUL, THP, RHOTM
     DIMENSION A(5),B(5),C(5),AA(5),BB(5),CC(5),AAA(5),BBB(5),CCC(5),

    VD(5),E(5),G(5),DA(100)
     DATA (A(I),I=1,5)/.961729, .052676, .17996, .108387, .022224/
     DATA (B(I),I=1,5)/4.28577, .222, .509048, .653052, .81402/
     DATA (C(I),I=1,5)/4.74133, .250008, .409772, .409772, .334969/
     DATA (AA(I),I=1,5)/.957448, .062721, .201257, .138803, .050525/
     DATA (BB(I),I=1,5)/4.29955, .292137, .584971, .530757, .691175/
     DATA (CC(I),I=1,5)/4.82121, .385293, .539591, .539591, .46745/
     DATA (AAA(I),I=1,5)/.0344006, .0728001, .1368, .13, .079999/
     DATA (BBB(I),I=1,5)/.239203, .3784, .4928, .481, .562003/
     DATA (CCC(I),I=1,5)/.448004, .572802, .6232, .631, .600998/
     DATA (D(I),I=1,5)/-.29093,-.28915,-.20092,-.092062,-.075481/
     DATA (E(I),I=1,5)/-.3407,-.060579, .45461, .461834, .456419/
     DATA (G(I),I=1,5)/-1.6256,-1.0725,-.63827,-.63827,-.65665/

     IF(CHI-1.E+2)1,1,2
   1 ELX=ALOG10(CHI)
     IF(.001-CHI)3,3,5
   5 NA=0.0
     GO TO 6
   3 NA=4.+ELX
     GO TO 6
   2 CHI=99.99
     GO TO 1
   6 IF(NA)7,7,8
```

Fig. A-3. Program 5-1, Listing (con't)

```
 7 PHI=1.
   GO TO 11
 8 IF(RELP-2000.)15,15,16
15 IF(RELP-2000.)17,17,18
16 IF(RELP-2000.)18,18,19
17 X=ELX*(ELX*A(NA)+B(NA))+C(NA)
   PHI=10.**X
   GO TO 11
18 X=ELX*(ELX*AA(NA)+BB(NA))+CC(NA)
   PHI=10.**X
   GO TO 11
19 X=ELX*(ELX*AAA(NA)+BBB(NA))+CCC(NA)
   PHI=10.**X
11 IF(NA)12,12,13
12 RLP=10.**ELX
   DRLDX=10.**ELX/CHI
   GO TO 14
13 RLP=ELX*(ELX*D(NA)+E(NA))+G(NA)
   RLP=10.**RLP
   DRLDX=RLP*(2.*ELX*D(NA)+E(NA))/CHI
14 RETURN
   END


    SUBROUTINE C1N2 (INDIC)

    IF INDIC=0, C1N2 WILL CALCULATE ALL CONSTANTS
    IF INCIC=1, C1N2 WILL NOT CALCULATE C1 AND C2
    IF INDIC=2, C1N2 WILL NOT CALCULATE C1, C2, FH, OR FAH

    COMMON EMA, EMB, THETAP, FA, ALFAA, RHOM, THETAM, FAX, RHOX,
   1THETAX, FB, ALFAB, FBX, TM, EMX, TX, C1, C2, TSTAR, ELH, FNK,
   2FINTH, DELTAR, ZZ, CAPN, WOOT, QALSTR, WTM, Z, DO, DI, VF, VG,
   3FHH, HA, HB, TAA, TAB, FH, FAH, ELE, C3, PSTAR, CPL, CPG, RHOL,
   4FMUG, FMUL, THP, RHOTM

    IF (INDIC .EQ. 1) GO TO 113
    IF (INDIC .EQ. 2) GO TO 13
    C1 = .1713E-8 * (EMA+EMB)
    P = 3.1415926/180.
    C2 = 443.*(ALPHAA*COS(P*THETAP)+FA*ALPHAA*RHOM*COS(P*THETAM)
   V  +FAX*ALPHAA*RHOX*COS(P*THETAX)+FB*ALPHAB*RHOM*COS(P*THETAM)
   V  +FBX*ALPHAB*RHOX*COS(P*THETAX))
   V  +TM**4*.1713E-8*(FA*EMA+FB*EMB)*EPSM
   V +EMX*TX**4*.1713E-8*(FAX*EMA+FBX*EMB)
   V  + .01*(EMA+EMB)
113 FH=(ELH**2*(HA+HB))/(FNK*FINTH)
    FAH=(ELH**2*(HA*TAA+HB*TAB))/(FNK*FINTH*TSTAR)
 13 IF (C1 .NE. 0.0) C3=C2/(C1*TSTAR**4)
    RETURN
    END
```

Fig. A-3. Program 5-1, Listing (con't)

```
   SUBROUTINE DECRD(DATA)
   READS A VARIABLE NUMBER OF ITEMS OF FLOATING-POINT DATA INTO
   SPECIFIED ELEMENTS OF AN ARRAY IN BLOCKS OF 5 CONSECUTIVE ITEMS.
   ONE OR MORE BLANK FIELDS ON A DATA CARD CAUSE THE VALUES IN CORE
   TO REMAIN UNCHANGED
   THE FORTRAN INTEGER INDEX IN THE FIRST FIELD OF EACH CARD DEFINES
   THE POSITION OF THE ARRAY OF THE FIRST ITEM OF EACH BLOCK OF FIVE.
   THE BLOCKS NEED NOT BE SEQUENTIAL NOR CONTINUOUS.
   THE INDEX IS PLACED AT THE END OF ITS FIELD.  IT MAY NOT BE ZERO
   OR BLANK.  IT SHALL NOT CONTAIN A DECIMAL POINT.
   A DECIMAL POINT MUST ALWAYS BE PLACED IN EACH DATA ITEM, THEREFORE
   THE VALUE MAY BE PLACED ANYWHERE IN EACH OF THE FIELDS PER CARD.
   THE DECIMAL SCALE, IF ANY, FOR A DATA ITEM MUST BE PLACED AT THE
   END OF THE FIELD.
   A  0.  MUST BE ENTERED TO READ IN A ZERO. A  -0.  IS THE SAME AS A
   BLANK FIELD. THE READING OF DATA IS TERMINATED BY ENTERING A
   NEGATIVE INDEX ON THE LAST CARD OF EACH SERIES.
   TO USE THE ROUTINE ---- CALL DECRD(DATA)
   DIMENSION DRBU (5), DATA (6)
 1 READ 2, IND, (DRBU(I),I=1,5)
 2 FORMAT(I12, 5E12.0)
   IF (IND. EQ. (-999)) STOP
 3 J = IABS(IND)
 4 DO 7 I=1,5
 5 IF(DRBU(I)) 6,10,6
 6 DATA(J) = DRBU(I)
 7 J = J+1
 8 IF(IND) 9,11,1
 9 RETURN
10 IF(SIGN(1.,DRBU(I))) 7,11,6
11 CALL EXIT
   END

   SUBROUTINE TEMP (T2)

   COMMON EMA, EMB, THETAP, FA, ALFAA, RHOM, THETAM, FAX, RHOX,
  1THETAX, FB, ALFAB, FBX, TM, EMX, TX, C1, C2, TSTAR, ELH, FNK,
  2FINTH, DELTAR, ZZ, CAPN, WOOT, QALSTR, WTM, Z, DO, DI, VF, VG,
  3FHH, HA, HB, TAA, TAB, FH, FAH, ELE, C3, PSTAR, CPL, CPG, RHOL,
  4FMUG, FMUL, THP, RHOTM

   C10=C1
   C20=C2
   HAT=(HA*TAA+HB*TAB)
   PI=3.14159
   AREA=(DO*PI-2.*DELTAR)/2.
   A=C1*2.*ELE+C10*DO
   B=(HA+HB)*(2.*ELE+AREA)
   C=(-C2-HAT)*2.*ELE-C20*DO-HAT*AREA
   T1=TSTAR
   DO 19 I=1,100
   T2=T1-(A*T1**4+B*T1+C)/(4.*A*T1**3+B)
   IF (ABS(T2-T1) .LT. .001) RETURN
19 T1=T2
   PRINT 1
 1 FORMAT (" SUBROUTINE TEMP DID NOT CONVERGE")
   CALL EXIT
   END
```

Fig. A-3. Program 5-1, Listing (con't)

```
      SUBROUTINE OUT

      COMMON EMA, EMB, THETAP, FA, ALFAA, RHOM, THETAM, FAX, RHOX,
     1THETAX, FB, ALFAB, FBX, TM, EMX, TX, C1, C2, TSTAR, ELH, FNK,
     2FINTH, DELTAR, ZZ, CAPN, WDOT, QALSTR, WTM, Z, DO, DI, VF, VG,
     3FHH, HA, HB, TAA, TAB, FH, FAH, ELE, C3, PSTAR, CPL, CPG, RHOL,
     4FMUG, FMUL, THP, RHOTM

      PRINT 90
   90 FORMAT (" ",10X,"INPUT DATA"//)
      PRINT 91, TSTAR, PSTAR, WDOT, QALSTR
   91 FORMAT (" ",F14.5,5X,"FLUID TEMPERATURE, DEGREES R"/
     1F15.5,5X,"FLUID ENTERY PRESSURE,LB/SQFT"/
     2F15.5,5X,"FLOW RATE, LB/HR"/F15.5,5X,"WEIGHT FRACTION OF VAPOR"/)
      PRINT 92, CPL, FMUL, RHOL, FHH
   92 FORMAT (     F15.5,5X,"SPECIFIC HEAT OF LIQUID, BTU/LB-DEGREFS R"/
     1F15.5,5X,"VISCOSITY OF LIQUID, LB/SEC-FT"/F15.5,5X,
     2"DENSITY OF LIQUID, LB/CUFT"/F15.5,5X,"LATENT HEAT OF FLUID, BTU/L
     3B"/)
      PRINT 94, CPG, FMUG, WTM, Z
   94 FORMAT (     F15.5,5X,"SPECIFIC HEAT OF GAS, BTU/LB-DEGREESR"/
     1F15.5,5X,"VISCOSITY OF GAS, LB/SEC-FT"/
     2F15.5,5X,"MOLECULAR WEIGHT OF GAS, LB/MOL"/F15.5,5X,
     3"CORRECTION FACTOR FOR IDEAL GAS FORMULA"/)
      PRINT 912, DI, DO, CAPN
  912 FORMAT (     F15.5,5X,"INSIDE DIAMETER OF TUBE, FT"/
     1F15.5,5X,"OUTSIDE DIAMETER OF TUBE, FT"/F15.5,5X,
     2"NUMBER OF TUBES"/)
      PRINT 93, FNK, FA, FB, ALFAA, ALFAB, EMA, EMB
   93 FORMAT (                           F15.5,5X,"THERMAL CONDUCTIVITY OF FIN
     1 MATERIAL (BTU/FT.HR.R)"/F15.5,5X,"FORM FACTOR BETWEEN SIDE A AND
     2MOON"/F15.5,5X,"FORM FACTOR BETWEEN SIDE B AND MOON"/F15.5,5X,
     3"ABSORBTIVITY, SIDE A"/F15,5,5X,"ABSORBTIVITY, SIDE B"/
     4F15.5,5X,"EMISSIVITY, SIDE A"/F15,5,5X,"EMISSIVITY, SIDE B")
      PRINT 95, FAX, FBX, TX, THETAX, RHOX
   95 FORMAT (F15.5,5X,"FORM FACTOR BETWEEN SIDE A AND X"/F15.5,5X,
     1"FORM FACTOR BETWEEN SIDE B AND X"/F15.5,5X,"TEMPERATURE OF X (DEG
     2REES R)"/F15.5,5X,"ANGLE BETWEEN SUNS RAYS AND NORMAL TO X (DFGREE
     3S)"/F15.5,5X,"REFLECTIVITY OF X")
      PRINT 96, TM, THETAM, RHOM
   96 FORMAT (F15.5,5X,"TEMPERATURE OF MOON (DEGREES R)"/F15.5,5X,
     1"ANGLE BETWEEN SUNS RAYS AND NORMAL TO MOON SURFACE (DEGREES)"/
     2F15.5,5X,"REFLECTIVITY OF MOON SURFACE")
      PRINT 97, THP, FINTH, DELTAR, ELH
   97 FORMAT (F15.5,5X,"ANGLE BETWEEN SUNS RAYS AND PLANE OF EXTENDED SU
     1RFACE"/F15.5,5X,"ROOT THICKNESS,              (FEET)  "/F15.5,5X,
     2"RATIO OF END TO ROOT SECTION"/F15.5,5X,"LENGTH OF FIN (FEET)"/)
      PRINT 98, HA, HB, TAA, TAB
   98 FORMAT (F15.5,5X,"CONVECTION CUEFFICIENT SIDE A (BTU/HR.SQFT.R)"/
     1F15.5,5X,"CONVECTION COEFFICIENT SIDE B (BTU/HR.SQFT.R)"/F15.5,5X,
     2"FLUID TEMPERATURE SIDE A (DEGREES R)"/F15.5,5X,"FLUID TEMPERATURE
     3 SIDE B (DEGREES R)"//)
      SC1=C1*1.0E08
      PRINT 99, SC1, C2
   99 FORMAT (F15.5,5X,"X10E-08",5X,"C1 (BTU/HR.SQFT.R**4)"/F15.5,5X,
     1"C2 (BTU/HR.SQFT.) "///)
      PRINT 910
  910 FORMAT (" NONDIMENSIONAL PARAMETERS"/)
      PRINT 911, ZZ    , C3, FH, FAH
  911 FORMAT (F15.5,5X,"ZETA P  PROFILE NUMBER"/F15.5,5X,"C3 ENVIRONMENT
```

Fig. A-3. Program 5-1. Listing (con't)

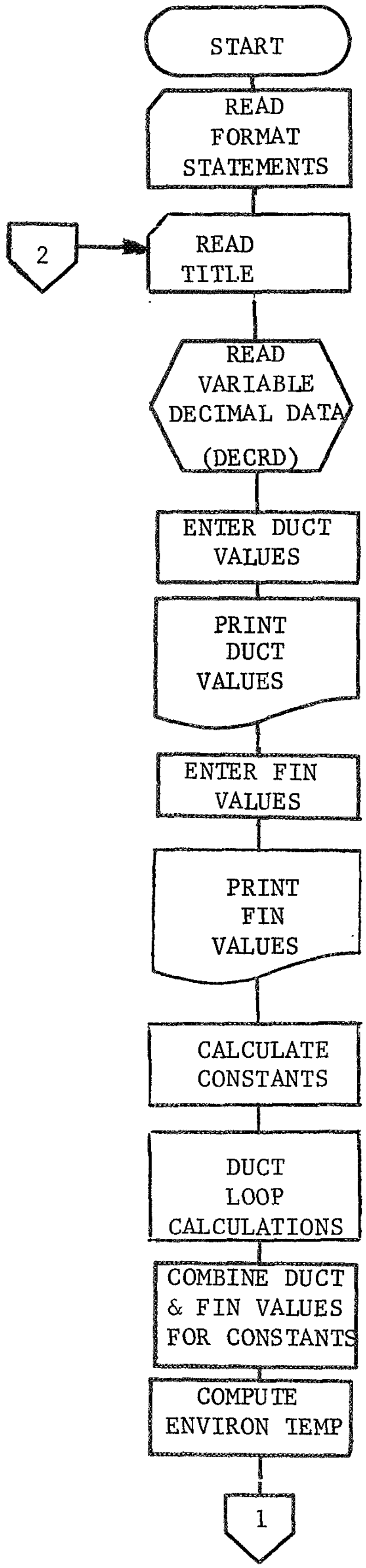
```
   1AL PARAMETER"/F15.5,5X,"FH  SURFACE CONVECTIVE PARAMETER"/F15.5,
   25X,"FAH  ENVIRONMENT CONVECTIVE PARAMETER"//)
    RETURN
    END


    SUBROUTINE ENTGRI

    COMMON EMA, EMB, THETAP, FA, ALFAA, RHOM, THETAM, FAX, RHOX,
   1THETAX, FB, ALFAB, FBX, TM, EMX, TX, C1, C2, TSTAR, ELH, FNK,
   2FINTH, DELTAR, ZZ, CAPN, WDOT, QALSTR, WTM, Z, DO, DI, VF, VG,
   3FHH, HA, HB, TAA, TAB, FH, FAH, ELE, C3, PSTAR, CPL, CPG, RHOL,
   4FMUG, FMUL, THP, RHOTM
    DIMENSION CM(5),F )(5), T(5), A(3), B(3), C(3)

    DATA (A(I),I=1,3)/ .41199999 , .0053315, .00002362/
    DATA (B(I),I=1,3)/-.87831999, -.0962565, -.00405435/
    DATA (C(I),I=1,3)/ 1.0, .6246049, .23347166/

    D2Z(T2,T4,T5)=(T5*(1.-DELTAR)+ZETAP*(T4**4-C3)+FH*T4-FAH)/
   V(1.-T2*(1.-DELTAR))
    ZETAP=ZZ
    IF (ZETAP-100.) 126, 125, 125
125 NA=3
    GO TO 127
126 IF (ZETAP) 128, 129, 128
128 NA=2+ALOG10(ZETAP)
    IF (NA .LT. 1)  NA=1
127 EFR1=(1.-C3)*(ZETAP*(ZETAP*A(NA)+B(NA))+C(NA))
129 IF (FH .NE. 0.0) EFC1=TANH(SQRT(FH))/SQRT(FH)
    T(5)=-ZETAP*EFR1-(FH-FAH)*EFC1
    IF (ZETAP .EQ. 0.0)  GO TO 1400
    ITER = 0
    ITLT=15.
    ISU=0
    ISW=0
    DZ0=0.
    DZW=0.
    DZ1A=T(5)
050 WILT = 500.
    T(4) = 1.
061 T(3)=1./25.
    T(2) = 0.
    MESH=25.
    DZ1=T(5)
    ITER=ITER+1
    IF (ITLT - ITER) 1125,1130,1130
125 PRINT 1500,DZ1A,DZ1
500 FORMAT(38H0INTEGRATION CONVERGENCE FAILED. DZ1A=E12.5,5H DZ1=
   V  E12.5)
    RETURN
130 DO 1390    J=1,MESH
    FO(2)=0.
    FO(3)=T(3)/2.
    FO(4)=T(3)/2.
    FO(5)=T(3)
    CM(1)=0.
    DO 2  I=2,5
```

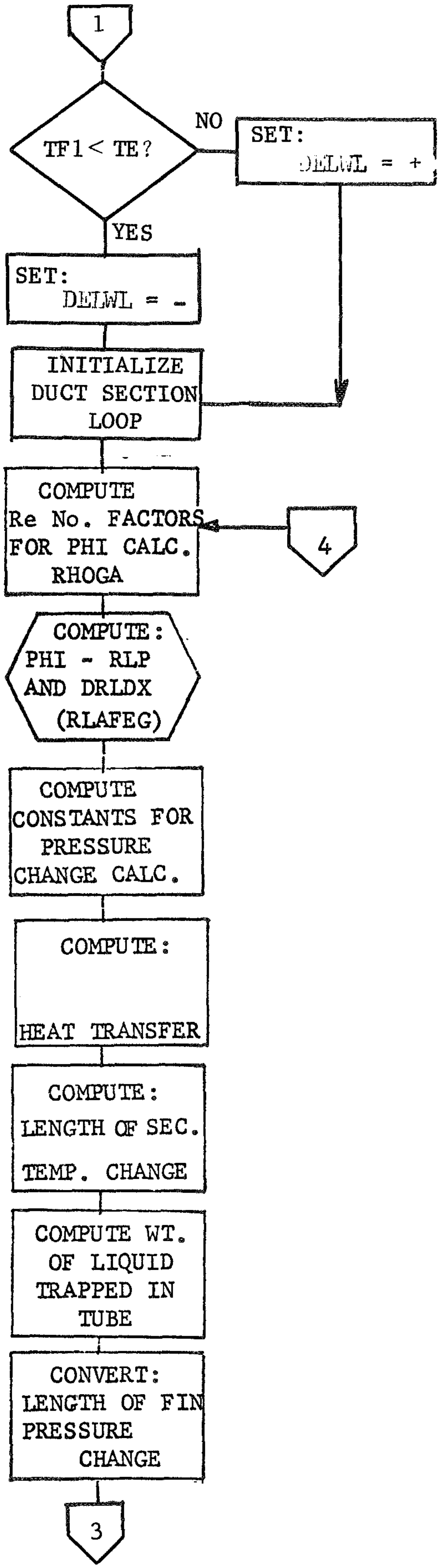
Fig. A-3. Program 5-1, Listing (con't)

```
      CM(I)=DZZ(T(2)+FO(I),T(4)+FO(I)*T(5),T(5)+FO(I)*CM(I-1))
    2 CONTINUE
      T(2)=T(2)+T(3)
      DT4  =T(3)/6.*(CM(2)+CM(3)+CM(4))*T(3)+T(3)*T(5)
      T(4)=T(4)+DT4
      DT5  =T(3)/6.*(CM(2)+2.*CM(3)+2.*CM(4)+CM(5))
      T(5)=T(5)+DT5
 1200 IF(ABS(DZ1)+ABS(T(5))-ABS(DZ1+T(5)))1250,1250,1205
 1205 IF(ISW)1225,1235,1225
 1225 DZ0=DZ1
      T(5)=.5*(DZ0+DZW)
      GO TO 1210
 1235 DZ0=DZ1
      T(5)=1.10*DZ1
      IF(ISW)1210,1239,1210
 1210 IF((ABS(DZW)-ABS(DZ0))/ABS(T(5))-.0025)1400,1400,1239
 1239 ISO=1
      IF(ITLT-ITER) 1125,1125,1050
 **** TEST FOR WILT
 1250 IF (ABS (WILT)-ABS (T(5))) 1260, 1380,1380
 1260 IF(ISO)1278,1277,1278
 1277 T(5)=.90*DZ1
      DZW=DZ1
      GO TO 1265
 1278 DZW=DZ1
      T(5)=.5*(DZ0+DZW)
 1265 IF((ABS(DZW)-ABS(DZ0))/ABS(T(5))-.0025)1400.1400,1270
 1270 ISW=1
      IF(ITLT-ITER) 1125,1125.1050
 1380 WILT=T(5)
 1390 CONTINUE
      GO TO 1260
 1400 ELE=-ELH*T(5)/(ZETAP*(1.-C3)+FH-FAH)
      RETURN
      END
```

```
       DATA FOR PROBLEMS
       POTASSIUM CONDENSER  6000 LB/HR   464 TUBES
                6.0083333  .25          1.21E-05   1.0E-04
               120.0       0.0
               39  4.      490.
                3 1620.
               10 .8       51.5      873.      39.1
               35 .3082E-080.0       .21       .183
                1 .05208   .0312               6000.     .16666
               45 .936      494.
       -       41  1.0      43.6               464.
       POTASSIUM CONDENSER  6000 LB/HR   120 TUBES
       -       44 120.
       POTASSIUM REHEATER   CONVECTIVE ENVIRONMENT
               44  464.
               14 2.       2.        2000.      2000.
               35 .001E-08
               -4  3000.
       POTASSIUM REHEATER   CONVECTIVE ENVIRONMENT
        -      16  1622.     1622.
       POTASSIUM CONDENSER CONVECTIVE AND RADIATIVE ENVIRONMENT
       -       35 .0500E-08
       END OF DATA
       -      999
```

Fig. A-3. Program 5-1, Listing (con't)


START
READ FORMAT STATEMENTS
2
READ TITLE
READ VARIABLE DECIMAL DATA (DECRD)
ENTER DUCT VALUES
PRINT DUCT VALUES
ENTER FIN VALUES
PRINT FIN VALUES
CALCULATE CONSTANTS
DUCT LOOP CALCULATIONS
COMBINE DUCT & FIN VALUES FOR CONSTANTS
COMPUTE ENVIRON TEMP
1


1
TF1 < TE?
NO
SET: DELWL = +
YES
SET: DELWL = -
INITIALIZE DUCT SECTION LOOP
COMPUTE Re No. FACTORS FOR PHI CALC. RHOGA
4
COMPUTE: PHI - RLP AND DRLDX (RLAFEG)
COMPUTE CONSTANTS FOR PRESSURE CHANGE CALC.
COMPUTE: HEAT TRANSFER
COMPUTE: LENGTH OF SEC. TEMP. CHANGE
COMPUTE WT. OF LIQUID TRAPPED IN TUBE
CONVERT: LENGTH OF FIN PRESSURE CHANGE
3

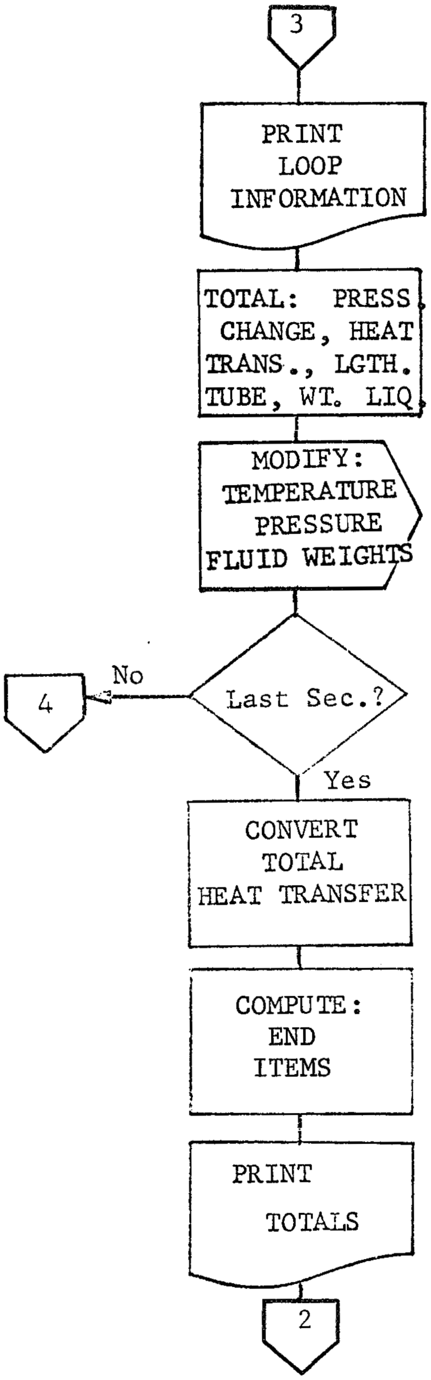


Fig. A-4. Program 5-2 Flow Diagram (cont.)

```
C       PROGRAM NO. 5-2 CONDENSER AND/OR EVAPORATOR ANALYSIS
C
       DIMENSION F1(12),F2(12),F3(24),F4(132),F5(24),F6(24),F7(12),F8(12)
      V,F9(24),F10(12),F11(24),F12(12),F13(24),F14(24),F15(12),F16(12),
      VF17(12),F18(24),F19(24),F20(24),F21(60),F22(36),F23(12),TITLE(16)
       DIMENSION DA(300),SR(6),SC(6),C1D(6),C2D(6),HD(6),TA(6),C1(10),
      VC2(10),HA(10),HB(10),TAA(10),TAB(10),FLE(10)
       EQUIVALENCE(DA(1),WDOT),(DA(2),ENT),
      1(DA(8),FMESH),(DA(9),PSTAR),(DA(10),TSTAR),(DA(11),QALSTR),
      2(DA(12),FHH),(DA(13),CPG),(DA(14),FMUG),(DA(15),WTM),(DA(16),Z),
      3(DA(17),RHOL),(DA(18),CPL),(DA(19),FMUL)
C
       READ 2,F1,F2,F3,F4,F5,F6,F7,F8,F9,F10,F11,F12,F13,F14,F15,F16,
      VF17,F18,F19,F20,F21,F22,F23
    2 FORMAT (12A6)
    5 READ 2400,TITLE
 2400 FORMAT (16A5)
      CALL DECRD (DA)
C     PRINT CASE DATA
      PRINT 2600,TITLE
 2600 FORMAT (1H1,16A5///)
      PRINT F4,(J,DA(J),J=1,19)
C
C     ENTER AND PRINT DUCT VALUES
      NP=30
      ND=DA(6)
      DO 100  I=1,ND
      SR(I)=DA(NP)
      SC(I)=DA(NP+1)
      C1D(I)=DA(NP+2)
      C2D(I)=DA(NP+3)
      HD(I)=DA(NP+4)
      TA(I)=DA(NP+5)
  100 NP=NP+10
      PRINT F5,(K,SR(K),K=1,ND)
      PRINT F6,(K,SC(K),K=1,ND)
      PRINT F7,(K,C1D(K),K=1,ND)
      PRINT F8,(K,C2D(K),K=1,ND)
      PRINT F9,(K,HD(K),K=1,ND)
      PRINT F10,(K,TA(K),K=1,ND)
C
C     ENTER AND PRINT FIN VALUES
      NF=DA(7)
      IF(NF.LE.0.0) GO TO 250
      N=90
      DO 200 L=1,NF
      C1(L)=DA(N)
      C2(L)=DA(N+1)
      HA(L)=DA(N+2)
      HB(L)=DA(N+3)
      TAA(L)=DA(N+4)
      TAB(L)=DA(N+5)
      FLE(L)=DA(N+6)
  200 N=N+10
```

Fig. A-5. Program 5-2, Listing

```
      PRINT F11,(K,C1(K),K=1,NF)
      PRINT F12,(K,C2(K),K=1,NF)
      PRINT F13,(K,HA(K),K=1,NF)
      PRINT F14,(K,HB(K),K=1,NF)
      PRINT F15,(K,TAA(K),K=1,NF)
      PRINT F16,(K,TAB(K),K=1,NF)
      PRINT F17,(K,ELE(K),K=1,NF)
  250 PRINT F19
C
C     CALCULATE SYSTEM CONSTANTS
      PI=3.1415926
      IF(DA(3)) 275,280,275
  275 PERIM=DA(3)
      AD=DA(4)
      DI=4.*AD/PERIM
      GO TO 295
  280 DI=DA(5)
      AD=PI*DI**2/4.
      PERIM=PI*DI
  295 W=WDOT/(ENT*3600.)
      GJ=778.*32.17
      GDI=32.17*DI
      GD1=0.
      GD2=0.
      GD3=0.
      SUM0=0.
      SUM1=0.
      SUM4=0.
      DO 300  I=1,ND
      GD1=GD1+SR(I)*C1D(I)
      GD2=GD2+SC(I)*HD(I)
  300 GD3=GD3+(SR(I)*C2D(I)+SC(I)*HD(I)*TA(I))
      IF(NF.LE.0.0) GO TO 550
      DO 500  L=1,NF
      SUM0=SUM0+ELE(L)*(HA(L)*TAA(L)+HB(L)*TAB(L)+C2(L))
      SUM1=SUM1+ELE(L)*(HA(L)+HB(L))
  500 SUM4=SUM4+ELE(L)*C1(L)
  550 CK0=-(GD3+SUM0)
      CK1=GD2+SUM1
      CK4=GD1+SUM4
C
C     COMPUTE ENVIRONMENT TEMP
      IF(CK1.LE.0.0) GO TO 675
      LC=0
      TE=TSTAR
  640 LC=LC+1
      IF (LC-25) 660,660,651
  651 PRINT F18,TE,CK0,CK1,CK4
      GO TO 5
  660 FE=CK0+CK1*TE+CK4*TE**4
      IF(ABS(FE)-.001)1003,1003,670
  670 DFEDTE=CK1+4.*CK4*TE**3
      TE=TE-FE/DFEDTE
      GO TO 640
  675 TE=SQRT(SQRT(-CK0/CK4))
```

Fig. A-5. Program 5-2, Listing (con't)

```
C
C       SECTION CONSTANTS
 1003 IF(QALSTR .GT. .98 .AND. TE .GT. TSTAR) GO TO 701
      IF (QALSTR .LT. .02 .AND. TE.LT. TSTAR) GO TO 702
      IF (ABS(TSTAR-TE) .LT. 5.) GO TO 703
      WL=(1.-QALSTR)*W
      WG=W-WL
      IF (TSTAR .GT. TE) GO TO 801
      DELWL=-WL/FMESH
      GO TO 802
  801 DELWL=WG/FMESH
  802 P=PSTAR
      T=TSTAR
      FJH=778.*FHH
      DPSUM=0.0
      ELW=0.0
      QSUM=0.0
      WLTSUM=0.0
      R=1544./ATM
      RHOGS=PSTAR/(TSTAR*R*Z)
      WL1=WL+DELWL/2.
      UFS=(WL/RHOL+WG/RHOGS)/AD
      UFS2=UFS**2
      PMS=W*UFS/(32.17*AD)
      EKS=UFS2/(2.*GJ)
      WG1=W-WL1
      MESH=FMESH
C
C       SECTION CALCULATIONS
      DO 37 J=1,MESH
      RHOGA=P/(R*T*Z)
      REGP=(4.*WG1)/(PERIM*FMUG)
      RELP=(4.*WL1)/(PERIM*FMUL)
      IF(REGP-2000.)28,28,29
   28 IF(RELP-2000.)30,30,31
   29 IF(RELP-2000.)32,32,33
   30 CHIC1=(FMUL*RHOGA)/(FMUG*RHOL)
      CHI=SQRT((WL1*CHIC1)/WG1)
      DCHI=W*CHI/(2.*WL1*WG1)
      F=16./REGP
      GO TO 34
   31 CHIC1=(.046*4.**.8)/(16.*(PERIM)**.8)*(RHOGA/RHOL)*(FMUL**.2/FMUG)
      CHI=SQRT((WL1**1.8/WG1)*CHIC1)
      DCHI=(1.8*WG1+WL1)*CHI/(2.*WG1*WL1)
      F=16./REGP
      GO TO 34
   32 CHIC1=(16.*(PERIM)**.8)/(.046*4.**.8)*(RHOGA/RHOL)*(FMUL/FMUG**.2)
      CHI=SQRT((WL1/WG1**1.8)*CHIC1)
      DCHI=((WG1+1.8*WL1)*CHI)/(2.*WG1*WL1)
      F=.046/REGP**.2
      GO TO 34
   33 CHIC1=(RHOGA/RHOL)*(FMUL/FMUG)**.2
      CHI=SQRT((WL1/WG1)**1.8*CHIC1)
      DCHI=(.9*W*CHI)/(WG1*WL1)
      F=.046/REGP**.2
```

Fig. A-5. Program 5-2, Listing (con't)

```
 34 CALL RLAFFG(CHI,PHI,RLP,DRLDX,REGP,RELP)
    RGP=1.-RLP
    V=WL1/(RLP*AD*RHOL)
    U=WG1/(RGP*AD*RHOGA)
    V2=V**2
    U2=U**2
    UP2=(WG1/(AD*RHOGA))**2.
    U2COEF=1.-((WG1*DCHI*DRLDX)/RGP)
    V2COEF=1.-((WL1*DCHI*DRLDX)/RLP)
    DPXF=-1.*(PHI**2*((2.*UP2*RHOGA*F)/GDI))
    DPMDW1=DRLDX*DCHI
    DPMDW2=2.-((DPMDW1*WG1)/RGP)
    DPMDW3=2.-((DPMDW1*WL1)/RLP)
    DPMDW4=RHOGA*U2*RGP*DPMDW2/(32.17*WG1)
    DPMDW5=RHOL*V2*RLP*DPMDW3/(32.17*WL1)
    DPMDWX=DPMDW4-DPMDW5
    DPC1=(CPL*WL1+CPG*WG1)*T/(FJH*RHOGA)
    QS=(CK0+CK1*T+CK4*T**4)/3600
    DX1=QS+DPC1*DPXF
    DX2=FHH-V2*V2COEF/GJ+U2*U2COEF/GJ-DPC1*DPMDWX+(U2-V2)/(2.*GJ)
    DX=DX2*DELWL/DX1
    IF(DX)35,35,36
 35 PRINT F22,DX1,DX2,T,TE,QS,DPC1,DPXF
    GO TO 5
 36 DP= DPMDWX*DELWL+DPXF*DX
    DELT= T*DP/(FJH*RHOGA)
    WLT=RHOL*AD*RLP*DX*ENT
    PRINT F20,RELP,V,REGP,U,QS,DX,DELT,DP
    T=T+DELT
    WL1=WL1+DELWL
    WG1=W-WL1
    DPSUM=DPSUM+DP
    P=P+DP
    IF(P.LE.0.0) GO TO 705
    ELW=ELW+DX
    QSUM=QSUM+QS*DX*ENT
    WLTSUM=WLTSUM+WLT
 37 CONTINUE
    QSUM=QSUM*3600.
    RHOGE=P/(T*R*Z)
    WLE=WL1-DELWL/2.
    WGE=W-WLE
    UFEND=(WLE/RHOL+WGE/RHOGE)/AD
    UFE2=UFEND**2
    PMEND=W*UFEND/(32.17*AD)
    DPM=PMS-PMEND
    EKEND=UFE2/(2.*GJ)
    PRINT F21,DPSUM,DPM,WLTSUM,QSUM,UFS,UFEND,ELW,PMS,PMEND,TE,EKS,
   VEKEND
    GO TO 5
701 PRINT F1,TE,TSTAR
    GO TO 5
702 PRINT F2,TE,TSTAR
    GO TO 5
703 PRINT F3,TE,TSTAR
    GO TO 5
705 PRINT F23,P,DPSUM
    GO TO 5
    END
```

Fig. A-5. Program 5-2, Listing (con't)

```
      SUBROUTINE RLAFEG (CHI,PHI,RLP,DRLDX,REGP,RELP)
C
      DIMENSION A(5),B(5),C(5),AA(5),BB(5),CC(5),AAA(5),BBB(5),CCC(5),
     VD(5),E(5),G(5),DA(300)
C
      DATA (A(I),I=1,5)/.961729, .052676, .17996, .108387, .022224/
      DATA (B(I),I=1,5)/4.28577, .222, .509048, .653052, .81402/
      DATA (C(I),I=1,5)/4.74133, .250008, .409772, .409772, .334969/
      DATA (AA(I),I=1,5)/.957448, .062721, .201257, .138803, .050525/
      DATA (BB(I),I=1,5)/4.29955, .292137, .584971, .530757, .691175/
      DATA (CC(I),I=1,5)/4.82121, .385293, .539591, .539591, .46745/
      DATA (AAA(I),I=1,5)/.0344006, .0728001, .1368, .13, .079999/
      DATA (BBB(I),I=1,5)/.239203, .3784, .4928, .481, .562003/
      DATA (CCC(I),I=1,5)/.448004, .572802, .6232, .631, .600998/
      DATA (D(I),I=1,5)/-.29093,-.28915,-.20092,-.092062,-.075481/
      DATA (E(I),I=1,5)/-.3407,-.060579, .45461, .461834, .456419/

      DATA (G(I),I=1,5)/-1.6256,-1.0725,-.63827,-.63827,-.65665/
      IF(CHI-1.E+2)1,1,2
    1 ELX=ALOG10(CHI)
      IF(.001-CHI)3,3,5
    5 NA=0.0
      GO TO 6
    3 NA=4.+ELX
      GO TO 6
    2 CHI=99.99
      GO TO 1
    6 IF(NA)7,7,8
    7 PHI=1.
      GO TO 11
    8 IF(REGP-2000.)15,15,16
   15 IF(RELP-2000.)17,17,18
   16 IF(RELP-2000.)18,18,19
   17 X=ELX*(ELX*A(NA)+B(NA))+C(NA)
      PHI=10.**X
      GO TO 11
   18 X=ELX*(ELX*AA(NA)+BB(NA))+CC(NA)
      PHI=10.**X
      GO TO 11
   19 X=ELX*(ELX*AAA(NA)+BBB(NA))+CCC(NA)
      PHI=10.**X
   11 IF(NA)12,12,13
   12 RLP=10.**ELX
      DRLDX=10.**ELX/CHI
      GO TO 14
   13 RLP=ELX*(ELX*D(NA)+E(NA))+G(NA)
      RLP=10.**RLP
      DRLDX=RLP*(2.*ELX*D(NA)+E(NA))/CHI
   14 RETURN
      END
```

Fig. A-5. Program 5-2, Listing (con't)

```
      SUBROUTINE DECRD(DATA)
C
C     READS A VARIABLE NUMBER OF ITEMS OF FLOATING-POINT DATA INTO
C     SPECIFIED ELEMENTS OF AN ARRAY IN BLOCKS OF 5 CONSECUTIVE ITEMS.
C     ONE OR MORE BLANK FIELDS ON A DATA CARD CAUSE THE VALUES IN CORE
C     TO REMAIN UNCHANGED
C     THE FORTRAN INTEGER INDEX IN THE FIRST FIELD OF EACH CARD DEFINES
C     THE POSITION OF THE ARRAY OF THE FIRST ITEM OF EACH BLOCK OF FIVE.
C     THE BLOCKS NEED NOT BE SEQUENTIAL NOR CONTINUOUS.
C     THE INDEX IS PLACED AT THE END OF ITS FIELD.  IT MAY NOT BE ZERO
C     OR BLANK.  IT SHALL NOT CONTAIN A DECIMAL POINT.
C     A DECIMAL POINT MUST ALWAYS BE PLACED IN EACH DATA ITEM, THEREFORE,
C     THE VALUE MAY BE PLACED ANYWHERE IN EACH OF THE FIELDS PER CARD.
C     THE DECIMAL SCALE, IF ANY, FOR A DATA ITEM MUST BE PLACED AT THE
C     END OF THE FIELD.
C     A  0.  MUST BE ENTERED TO READ IN A ZERO. A  -0.  IS THE SAME AS A
C     BLANK FIELD. THE READING OF DATA IS TERMINATED BY ENTERING A
C     NEGATIVE INDEX ON THE LAST CARD OF EACH SERIES.
C     TO USE THE ROUTINE ---- CALL DECRD(DATA)
      DIMENSION DRBU (5), DATA (6)
    1 READ 2, IND, (DRBU(I),I=1,5)
    2 FORMAT(I12, 5F12.0)
      IF (IND. EQ. (-999)) STOP
    3 J = IABS(IND)
    4 DO 7 I=1,5
    5 IF(DRBU(I)) 6,10,6
    6 DATA(J) = DRBU(I)
    7 J = J+1
    8 IF(IND) 9,11,1
    9 RETURN
   10 IF(SIGN(1.,DRBU(I))) 7,11,6
   11 CALL EXIT
      END
C
C     PERMANENT HOLLERITH DATA
C
(36H TEMPERATURE IS TOO HIGH TO CONDENSE/4H TE=F12.8,7H TSTAR=F12.8)
(36H TEMPERATURE IS TOO LOW TO EVAPORATE/4H TE=E12.8,7H TSTAR=E12.8)
(57H FLUID TEMPERATURE TOO CLOSE TO ENVIRONMENTAL TEMPERATURE/4H TE=E12.
8,7H TSTAR=E12.8)
      (11H INPUT DATA/I9,F15.8,26H TOTAL WEIGHT FLOW (LB/HR)/I9,F15.8,13
H NO. OF DUCTS/I9,F15.8,28H DUCT PERIMETER (FT) *OPTION/I9,F15.8,26H DUC
T AREA (SQ FT) *OPTION/I9,F15.8,32H EFFECTIVE DIAMETER (FT) *OPTION/ I9,
F15.8,21H NO. OF DUCT SECTIONS/I9,F15.8,12H NO. OF FINS/I9,F15.8,18H NO
OF SUBSECTIONS/I9,F15.8,26H INLET PRESSURE (LB/SQ FT)/I9,F15.8,27H FLUID
 TEMP AT ENTRANCE (R)/I9,F15.8,22H WEIGHT FRACTION VAPOR/I9,F15.8,30H LA
TENT HEAT OF FLUID (BTU/LB)/I9,F15.8,34H SPECIFIC HEAT OF VAPOR (BTU/LB
R)/I9,F15.8,31H VISCOSITY OF VAPOR (LB/SEC FT)/I9,F15.8,35H MOLECULAR WE
IGHT OF FLUID (LB/MOL)/I9,F15.8,29H VAPOR COMPRESSIBILITY FACTOR/I9,F15.
8,29H DENSITY OF LIQUID (LB/CU FT)/I9,F15.8,35H SPECIFIC HEAT OF LIQUID
(BTU/LB R)/I9,F15.8,32H VISCOSITY OF LIQUID (LB/SEC FT))
(//18H INPUT DUCT VALUES/    4H SEC5X,43H EFFECT PERIFERAL LENGTH FOR RA
DIATION (FT)/(I3,7X,F15.8))
(     4H SEC5X,44H EFFECT PERIFERAL LENGTH FOR CONVECTION (FT)/(I3,7X,
F15.8))
( 4H SEC5X,42H RADIATION CONSTANT C1 (BTU/HR SQ FT R**4)/(I3,7X,E15.8))
(     4H SEC5X,37H RADIATION CONSTANT C2 (BTU/HR SQ FT)/(I3,7X,F15.8))
(     4H SEC5X,48H CONVECTIVE HEAT TRANSFER COEFF (BTU/HR SQ FT R)/(I3,7X
,F15.8))
(     4H SEC5X,17H AMBIENT TEMP (R)/(I3,7X,F15.8))
(17H1INPUT FIN VALUES/    4H FIN5X,42H RADIATION CONSTANT C1 (BTU/HR SQ
FT R**4)/(I3,7X,E15.8))
```

Fig. A-5. Program 5-2, Listing (con't)

```
(     4H FIN5X,37H RADIATION CONSTANT C2 (BTU/HR SQ FT)/(I3,7X,F15.8))
(     4H FIN5X,55H CONVECTIVE HEAT TRANSFER COEFF SIDE A (BTU/HR SQ FT R)
/(I3,7X,F15.8))
(     4H FIN5X,55H CONVECTIVE HEAT TRANSFER COEFF SIDE B (BTU/HR SQ FT R)
/(I3,7X,F15.8))
(     4H FIN5X,24H AMBIENT TEMP SIDE A (R)/(I3,7X,F15.8))
(     4H FIN5X,24H AMBIENT TEMP SIDE B (R)/(I3,7X,F15.8))
(     4H FIN5X,19H EFFECT LENGTH (FT)/(I3,7X,F15.8))
(28H ENVIRON TEMP CONVERG FAILED/4H TE=E12.8,5H CK0=E12.8,5H CK1=E12.8,5
H CK4=E12.8)
(//12H OUTPUT DATA/1H0,12HRELP=  (LIQ),1X,9HV= FT/SEC,4X,12HREGP=  (VAP)
,1X,9HU= FT/SEC,4X,11HQS=BTU/SCFT,2X,6HDX= FT,7X,7HDELT= R,6X,7HDP= PSF)
(1H ,E12.5,1X,E12.5,1X,E12.5,1X,E12.5,1X,E12.5,1X,E12.5,1X,E12.5,1X,E12.
5,1X,E12.5)
(1H0,6HDPSUM=E12.5,9H LB/SQ FT,2X,5H DPM=E12.5,9H LB/SQ FT,2X,8H WLTSUM=
E11.5,3H LB/6H QSUM=E12.5,7H BTU/HR5X5H UFS=E12.5,9H FEET/SEC3X,6HUFEND=
E12.5,9H FEET/SEC/5H ELW=E12.5,5H FEET8X,,5H PMS=E12.5,9H LB/SQ FT, 2X,7
H PMEND=E12.5,9H LB/SQ FT/,4H TE=E13.5,2H R11X,5H KES=E12.5,7H BTU/LB,4X
,7H KEEND=E12.5,7H BTU/LB)
(16H FLOW EXCESSIVE./5H DX1=E12.5,9H BTU/SCFT, 5H DX2=E12.5,7H BTU/LB,3H
 T=E12.5,2H R/4H TE=E12.5,2H R,4H QS=E12.5,9H BTU/SCFT,6H DPC1=E12.5,9H
BTU/SCFT/6H DPXE=E12.5,9H BTU/SCFT)
(21H FLOW RATE EXCESSIVE./3H P=E12.5,4H PSF/7H DPSUM=E12.5,4H PSF)
C
C      DATA FOR PROBLEMS

       CONDENSER WITH NONCIRCULAR DUCT-2 LB/HR FLOW RATE
          12.           1.          .0518        .000111      0.00
          61.           2.          10.          1659.74      660.
         111.           977.9       .35             .8493E-0518.
         161.           60.3        1.005        .0002052
         30.0304        .0365          .1456E-0888.61         0.
         350.
         90    .1456E-0888.61       0.           0.           0.
         950.           .1559
        100    .1456E-0888.61       0.           0.           0.
-       1050.           .1559
       CONDENSER WITH NONCIRCULAR DUCT 1.5 LB/HR FLOW RATE
-         11.5          1.          .0518        .000111      0.00
       MULTI FIN FREON CONDENSER  75 LB/HR FLOW RATE
          175.          1.          0.           0.          .0375
          63.           3.          10.          3157.9      600.
         111.           61.31       .161         .00000746   187.39
         16.95          92.33       .218         .00029702
         30.03375       .03375         .1456E-08146.1         7.0
         35530.
         400.           0.          0.           0.           0.
         450.
         50.03375       .03375      0.           0.           12.
         55500.
         90    .1456E-08146.1       7.           12.          530.
         95500.         .186
        100    .1456E-08146.1       7.           0.           530.
        1050.           .349
        1100.           0.          12.          0.           500.
-       1150.           .2952
C
C      END CONTROL CARDS
C
       END OF PROBLEMS
         -999
```

Fig. A-5. Program 5-2, Listing (con't)

INFORMATION FOR PROGRAM USERS

DECRD (DECIMAL READ SUBROUTINE)

Description

This routine provides the facility for reading a variable number of pieces of floating point data into specified elements of an array; these elements may be either in sequential or in nonconsecutive locations. Only the information specified is actually read into storage.

The fixed point number (index) in the first field on each card defines the position of the first piece of data on the card. If the index is 1, the first piece of data will be stored in the first location reserved for the array; if it is 16, the first work will be placed in the 16th position, etc. The remaining fields on each card contain information for the successive locations of the array. If one or more fields are left blank, no information is read into the locations corresponding to these fields; the information already in these locations is unaltered.

Use

The decimal data will be read into storage by means of the FORTRAN statement, CALL DECRD (Name of array to be read).

The data are written in decimal data form which has 6 fields of width, 12 card-columns each.

a. The index or location number must be written to the extreme right of the first field; it may not be zero or blank.

b. The floating point data may be written in two ways on the data sheets:

  1. With a decimal point: 42.62 may be positioned anywhere in the field of width 12.
  2. With the E. type Format and the decimal point: .243 E02, where the exponent specification is written to the extreme right of the field.

c. Reading data are concluded by placing a negative sign in the first field of the last card to be read.

Restrictions

If any negative zero or ".0" is written as a piece of data, it will be recognized as a blank by FORTRAN. Zero should be designated by "0."

Error Indication

If a zero or blank index appears in the first field of a card, an error message is printed and the job is terminated.

Program Termination

Two cards are used to terminate a program. The first is a card with a title such as "End of Problems", the second has a -999 punched in columns 9 to 12. A test is provided in DECRD to terminate the program when these numbers appear.

NOTES ON PROGRAMS

1. Data numbers for the input variables are shown on pages 27, 28 and 29.
2. Data options are provided in both programs. In program 5-1 an

index (DA 41) is used to specify the option to be taken. If all radiation constants and convection parameters are to be calculated a "0" is entered. If C1 and C2 are entered in DA 35 and DA 36 a "1" is placed in DA 41. If pure parametric studies are to be made C1, C2, FH, and FAH are entered as input data in DA 35, 36, 47, and 48 respectively, and a "2" is entered in DA 41. In program 5-2 if non circular ducts are to be analyzed the duct perimeter and duct area must be entered in DA 3 and DA 4 respectively. If circular ducts are analyzed the internal diameter can be entered in DA 5 or the duct perimeter and area can be entered as for non circular ducts.

INPUT VARIABLES FOR PROGRAMS

DA	Program (5-1)	Program (5-2)
1	DO (outside diameter ft)	$\dot{w}$ (total weight flow, lb/hr)
2	DI (inside diameter ft)	ENT (no. of tubes)
3	T^* (inlet temp, R)	P (duct perimeter, ft)
4	$\dot{w}$ (total weight flow, lb/hr)	AD (duct area, sq ft)
5	ELH (fin length, ft)	DI (effective dia., ft)
6	FINTH (fin root th., ft)	ND (no of duct sect.)
7	DELTAR (thickness ratio)	NF (no of fins)
8	FMUG (gas viscosity, lb/ft-sec)	FMESH (no. of sub. sect.)
9	FMUL (liq. viscosity, lb/ft-sec)	P^* (inlet pressure, lb/ft^2)
10	QALSTR (inlet quality)	T^* (inlet temp, R)
11	FNK (fin k, Btu/hr-ft-R)	QALSTR (inlet quality)
12	FHH (latent heat, Btu/lb)	FHH (latent heat, Btu/lb)
13	WTM (mol wt, lb/mol)	CPG (spec. ht. of vap., Btu/lb)
14	HA (con. h.t. coef., Btu/hr ft^{2}R)	FMUG (gas viscosity, lb/ft-sec)
15	HB (con. h.t. coef., Btu/hr ft^{2}R)	WTM (mol. wt., lb/mol)
16	TAA (con. ambient temp., R)	Z (compressibility fac.)
17	TAB (con. ambient temp., R)	RHOL (liq. density lb/ft^3)
18	ALFAA (absorptivity side A)	CPL (spec. ht. of liq., Btu/lb R)
19	ALFAB (absorptivity side B)	FMUL (liq. viscosity lb/ft-sec)
20	EMA (emissivity side A)	
21	EMB (emissivity side B)	
22	EMX (emissivity body x)	

23 FA (view factor to m)

24 FAX (view factor to x)

25 FB (view factor to m)

26 FBX (view factor to x)

27 RHOM (reflectivity of m)

28 RHOX (reflectivity of x)

29 ZZ (profile no.)

30 THETAM (sun angle to m) (see listing below)

31 THEATX (sun angle to x)

32 TM (temp. of m, R)

33 TX (temp. of x, R)

34 EPSM (emissivity of m)

35 C1 (rad. const., Btu/hr ft^2 R^4)

36 C2 (rad. from env. Btu/hr ft^2)

37 CPG (spec. ht. of vap., Btu/lb R)

38 CPL (spec. ht. of liq., Btu/lb R)

39 FMESH (no. of sub. sec.)

40 PSTAR (inlet pres., lb/ft^2)

41 INDIC* (OPTION IND.)

42 RHOL (liq. density lb/ft^3)

43 THETAP (sun angle θ_p, deg.)

44 CAPN (no. of tubes)

45 Z (compressibility fact.)

46 RHOTM (density of tube, lb/ft^3)

47 FH (convective parameter)

48 FAH (convective parameter)

NP = 30, I = 0,5

NP + I	SR(I) (duct width for rad., ft.)
NP + I + 1	SC(I) (duct width for conv., ft)
NP + I + 2	C1D(I) (duct rad., Btu/hr ft^{2}R^4)
NP + I + 3	C2D(I) (duct rad. from env., Btu/hr ft^2)
NP + I + 4	HD(I) (conv. h.t. coef., Btu/hr ft^{2}R)
NP + I + 5	TA(I) (conv. ambient temp, R)

N = 90, L = 0,20

N + L	C1(L) (rad. const., Btu/hr ft^{2}R^4)
N + L + 1	C2(L) (rad. from env., Btu/hr ft^2)
N + L + 2	HA(L) (conv. h.t. coef., Btu/hr ft^{2}R)
N + L + 3	HB(L) (conv. h.t. coef., Btu/hr ft^{2}R)
N + L + 4	TAA(L) (conv. amb. temp, R)
N + L + 5	TAB(L) (conv. amb. temp., R)
N + L + 6	ELE(L) (equivalent length, ft)

APPENDIX B

SAMPLE PROBLEMS

Several sample problems are presented to demonstrate the capabilities and limitations of the programs. These problems are also useful for checkout should the program deck be reproduced or modified for use on another computer.

Three fluids, water, "Freon 113" and potassium were used in the problems. Some of them are reruns of those presented in Ref. 3 and some employ the configurations used in Ref. 1. This will permit the interested reader to make comparisons.

Problem 1: Potassium Space Powerplant Condenser

Two of the problems of Ref. 3 have been rerun as well as two cases with reduced numbers of tubes. Both programs 5-1 and 5-2 have been used for this example. A 6000 lb/hr case was run on program 5-1 and a 3000 lb/hr case was run on 5-2, however, when employing 5-1 the number of sections was reduced to four. The input and output for the 6000 lb/hr case is shown in Figs. B-1 and B-2 respectively. The 3000 lb/hr case is shown in Figs. B-3 and B-4. The calculated data using these programs agree closely with those of Ref. 3; the greatest discrepancy is in the value for the effective length, ELE. The value given in this report is considered to be the more accurate since it was obtained directly from a numerical integration procedure while the one in Ref. 3 was calculated from curve fit data. The difference is approximately two percent. The pressure for both cases is shown to increase as the fluid passes through the tubes. This is due to the fact that the momentum pressure rise is larger than the friction pressure drop. This may be surprising considering the fact that the fluid enters at a velocity of 459.31196 ft/sec for the 6000 lb/hr case. In spite of this high inlet velocity the tube length is still only 1.8459 feet. This short length demonstrates one of the big problems in designing a satisfactory space power plant condenser.

The results of using 120 and 100 tubes for the 6000 lb/hr case is shown in Fig. B-5. Reducing the number of tubes increases the fluid velocity and the associated pressure drop. It was impossible to completely analyze either of these cases. Calculations terminated after the second section for the case employing 120 tubes and after the first section for the 100 tubes. The reasons for the terminations are different. Pressure fell below zero for 120 tubes and the calculated section length was negative for 100 tubes. Both situations are impossible and both tests are needed in the programs to terminate useless calculations

Problem 2: Potassium Reheater

This problem uses much of the data of Problem 1 except that pure convective environments were selected. Two environments were chosen. In the first an ambient fluid at 2000°R was assumed. This is above the fluid inlet temperature of 1620. The inlet quality was held at 80 percent as in Problem 1. The input and output data are shown in Figs. B-6 and B-7. When the ambient was reduced to 1622 the output data was

```
    CALCULATED DATA

       0.15363      EFFECTIVE LENGTH OF FIN, FT.
    1622.00000      ENVIRONMENTAL TEMPERATURE, DEGREES R

 FLUID TEMPERATURE TOO CLOSE TO ENVIRONMENTAL TEMPERATURE
```

This check is provided in the program since the integration routine may get into difficulty if the temperatures of fluid and environment are nearly equal.

Problem 3: Potassium Condenser in Convective and Radiative Environments

This problem was chosen to test the ability of program (5-2) to handle an ususual situation. A low value was chosen for the radiation constant C_1 and an ambient convective temperature was chosen which was slightly above the fluid inlet temperature. As shown by Figs. B-8 and B-9, heat transfer by radiation outweighs the convection and heat is lost from the system. The reduced radiation coefficient C_1 accounts for the longer tube length required by this problem.

Problem 4: Tubular Heat Exchanger

Water is to be evaporated as it passes through a 3/8 inch O.D. tube. A low pressure gas having a low convective heat transfer coefficient surrounds the tube but high gas and wall temperatures are present. It is required to find the conditions in the evaporator, as the water passes through tube of sufficient length to completely evaporate the water.

In using Program 5-2 the values of the radiative and environmental parameters C_1 and C_2 are required. The problem conditions used to calculate these parameters are:

$$\epsilon_a = 0.6, \ \epsilon_x = 1.0, \ T_x = 1000 \text{ R and } F_{ax} = 1.0$$

Using these values in Eqs. (1.2) and (1.3)

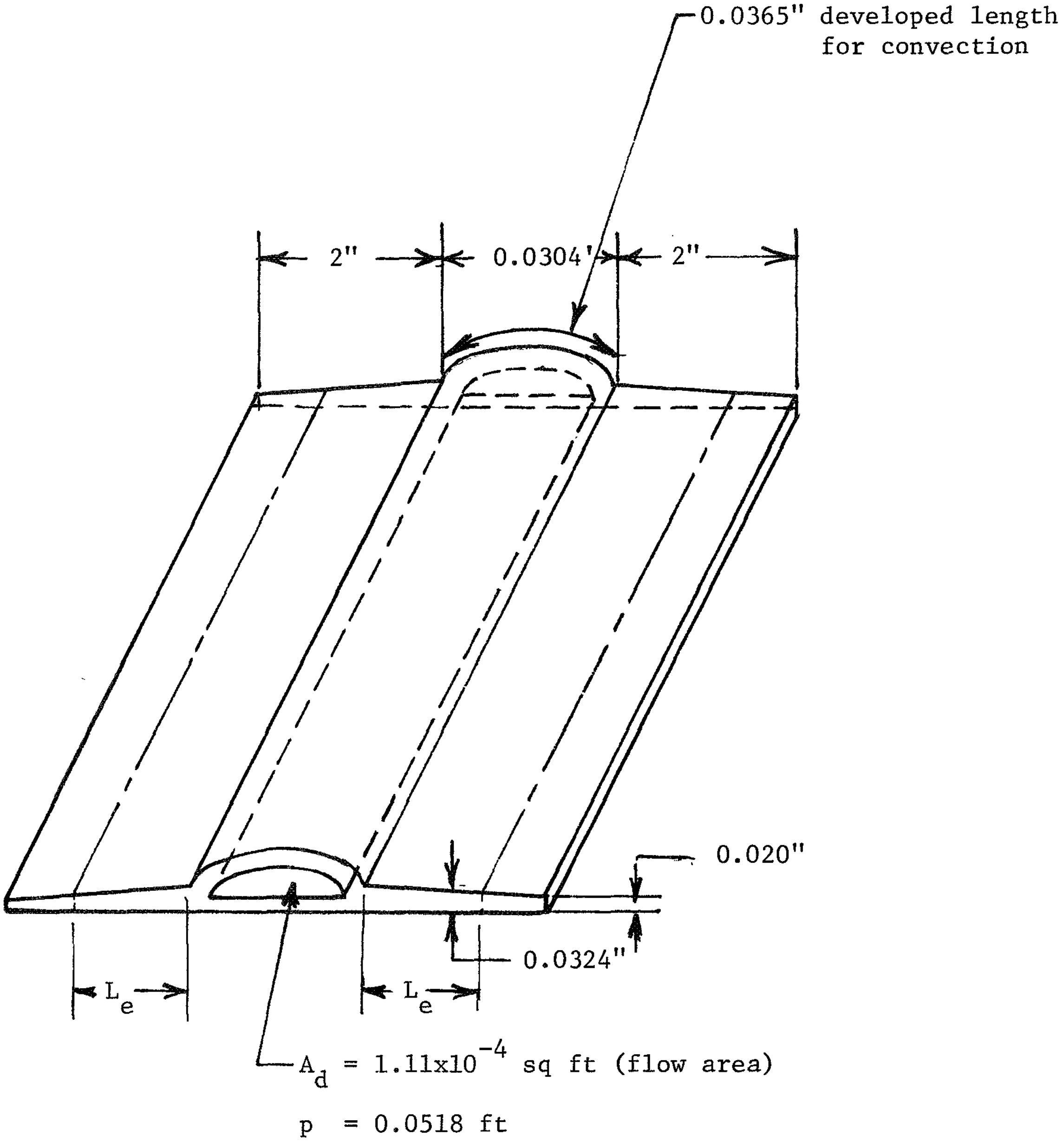
$$C_1 = \epsilon_a \sigma = (0.8)(0.1613)(10^{-8})$$

$$C_2 = 0.1713(10^{-8})(1000^4)(1.0)(0.6) = 1028$$

Two flow rates, 2.5 and 10 lb/hr, were chosen for this illustration. The remaining input items are shown in Fig. B-10. While the output for the two cases is shown in Fig. B-11. The analysis was sucessful for the 2.5 lb/hr flow rate, but the program ran into difficulty with the higher flow rate. The calculated pressure in the tube at the end of the eighth section was -1521.5 lb/sq. ft. and the program stopped the analysis. Fluid pressure drop in the turbulent regime is substantially higher than in the laminar region. The Reynolds numbers for vapor are shown to be in the turbulent region for all but the first section. Pressure drop for two phase flow is high when compared with single phase flow for either liquid or vapor. It is therefore easy to underestimate the actual pressure drop. In this case the final Reynold's number was 12,975--a value well in the turbulent region but not impossible in many flow problems. Observe also the impossible predicted temperature drop of 2136.9 degrees R in the last section analyzed. This is far from the expected range of only a few degrees of deviation from the inlet temperature. Lowering the flow rate to 2.5 lb/hr reduces the pressure drop to 73.382 lb/sq ft. This drop is only 2.3 percent of the calculated drop associated with approximately 80% of the heat transfer at the higher rate. One should remember that a portion of this difference is due to the difference in tube lengths. The duct length is approximately proportional to the flow rate and the pressure drop is approximately proportional to the length. The higher rate being four times the lower would indicate approximately four times the amount of heat exchange and four times the amount of duct length.

Problem 5: Condenser with Noncircular Duct

Problem 5, illustrated in Sketch 1, also uses Program 5.2.



0.0365" developed length for convection

$A_d = 1.11 \times 10^{-4}$ sq ft (flow area)

$p = 0.0518$ ft

Fluid - 2 lb/hr of steam

Material - Aluminum - k = 118 Btu/hr ft R

$T_{f_1} = 660$ R

$L_e = 0.1559'$ (calculated by Program 2-1 and shown in Figs. B-6 and B-7 of Ref. 1)

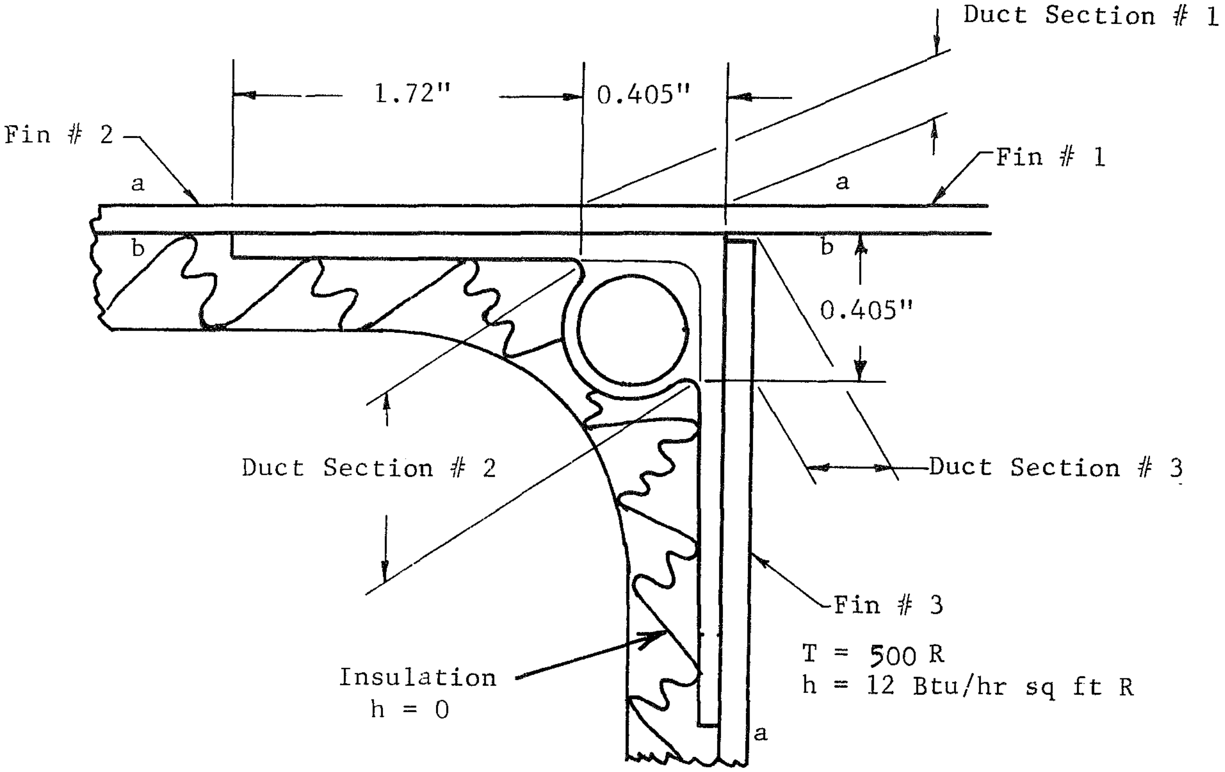
<u>Sketch 1</u>

The input and output data for this problem are shown in Figs. B-12 and B-13. Two flow rates were considered, 1.5 and 2 lb/hr. However, the later flow was excessive and the analysis was stopped after seven of the ten sections had been analyzed. For the lower flow rate, the pressure drop in the first five sections is shown to be considerably higher than in the last five sections. This is due to the turbulent Reynold's number's calculated for the vapor. Even with the lower flow rate the pressure drop is quite high (477.25 lb/sq ft). With the uncertainties involved in using equivalent diameter for calculating two phase flow pressure drop, and since the program ignores the entrance losses that come with any design, the acceptance of this flow rate should be questioned unless actual testing proves otherwise.

Problem 6: Multi Fin Freon Condenser

A coil carrying "Freon 113" is brazed into a tank structure as shown with much of the data in the Sketch 2. The coil itself has a 1/2" outside diameter, and a 0.025" thick wall.

The fin input and output data approximating the problem conditions is shown in Figs. B-10, B-11 and B-12 of Ref 1. The final input and output problem data from program 5-2 is shown in Figs. B-14 and B-15. For this problem two flow rates of 75 and 225 lb/hr were chosen.



System

T_{f_1} = 600 R "Freon 113"

L_e = 0.186 ft. (fin 1)

= 0.349 ft. (fin 2)

= 0.2952 ft. (fin 3)

Fin #1 and Fin#2

$T_m = T_a$ = 530 R

h_a = 7 Btu/hr sq ft R

$C_1 = 0.1456 \times 10^{-8}$

C_2 = 146.1 Btu/hr sq ft

Sketch 2

The problem demonstrates the wide capabilities of the program, the manner in which the data might be examined, and the configurations chosen to attain a suitable performance compromise.

Interesting data is printed out for section 9 and 10 for the 75 lb/hr flow rate. The pressure drop for section 9 is negative while all other sections are positive. In a condenser the vapor velocity decreases as more liquid is formed. This would appear to steadily lower the pressure drop from duct inlet to outlet. The fluid momentum goes down as the vapor condenses. This factor gives a pressure increase to the fluid. For the first eight sections the momentum rise is higher than the friction pressure drop and each section has a positive value for ΔP. In the ninth section the liquid Reynold's number exceeded 2000 and the flow was considered turbulent by the program. The turbulent-turbulent combination produced a higher pressure drop. In the tenth section, however, the friction pressure drop was again reduced in value and the momentum force was again predominant and gave a slight pressure rise. The overall pressure rise for the duct is shown to be 1.837 lb/sq. ft.

```
POTASSIUM CONDENSER  6000 LB/HR   464 TUBES

        INPUT DATA


  1620.00000      FLUID TEMPERATURE, DEGREES R
   490.00000      FLUID ENTERY PRESSURE,LB/SQFT
  6000.00000      FLOW RATE, LB/HR
     0.80000      WEIGHT FRACTION OF  VAPOR

     0.18300      SPECIFIC HEAT OF LIQUID, BTU/LB-DEGREES R
     0.00010      VISCOSITY OF LIQUID, LB/SEC-FT
    43.60000      DENSITY OF LIQUID, LB/CUFT
   873.00000      LATENT HEAT OF FLUID, BTU/LB

     0.21000      SPECIFIC HEAT OF GAS, BTU/LB-DEGREESR
     0.00001      VISCOSITY OF GAS, LB/SEC-FT
    39.10000      MOLECULAR WEIGHT OF GAS, LB/MOL
     0.93600      CORRECTION FACTOR FOR IDEAL GAS FORMULA

     0.03120      INSIDE DIAMETER OF TUBE, FT
     0.05208      OUTSIDE DIAMETER OF TUBE, FT
   464.00000      NUMBER OF TUBES

    51.50000      THERMAL CONDUCTIVITY OF FIN MATERIAL (BTU/FT.HR.R)
     0.00000      FORM FACTOR BETWEEN SIDE A AND MOON
     0.00000      FORM FACTOR BETWEEN SIDE B AND MOON
     0.00000      ABSORBTIVITY, SIDE A
     0.00000      ABSORBTIVITY, SIDE B
     0.00000      EMISSIVITY, SIDE A
     0.00000      EMISSIVITY, SIDE B
     0.00000      FORM FACTOR BETWEEN SIDE A AND X
     0.00000      FORM FACTOR BETWEEN SIDE B AND X
     0.00000      TEMPERATURE OF X (DEGREES R)
     0.00000      ANGLE BETWEEN SUNS RAYS AND NORMAL TO X (DEGREES)
     0.00000      REFLECTIVITY OF X
     0.00000      TEMPERATURE OF MOON (DEGREES R)
     0.00000      ANGLE BETWEEN SUNS RAYS AND NORMAL TO MOON SURFACE (DEGREES)
     0.00000      REFLECTIVITY OF MOON SURFACE
     0.00000      ANGLE BETWEEN SUNS RAYS AND PLANE OF EXTENDED SURFACE
     0.00833      ROOT THICKNESS,              (FEET)
     0.25000      RATIO OF END TO ROOT SECTION
     0.16666      LENGTH OF FIN (FEET)

     0.00000      CONVECTION COEFFICIENT SIDE A (BTU/HR.SQFT.R)
     0.00000      CONVECTION COEFFICIENT SIDE B (BTU/HR.SQFT.R)
     0.00000      FLUID TEMPERATURE SIDE A (DEGREES R)
     0.00000      FLUID TEMPERATURE SIDE B (DEGREES R)


     0.30820      X10E-08      C1 (BTU/HR.SQFT.R**4)
     0.00000      C2 (BTU/HR.SQFT.)


 NONDIMENSIONAL PARAMETERS

     0.84804      ZETA P  PROFILE NUMBER
     0.00000      C3 ENVIRONMENTAL PARAMETER
     0.00000      FH  SURFACE CONVECTIVE PARAMETER
     0.00000      FAH  ENVIRONMENT CONVECTIVE PARAMETER
```

Fig. B-1. Problem 1, Input Data

```
CALCULATED DATA

  0.08824       EFFECTIVE LENGTH OF FIN, FT.
  0.00290       ENVIRONMENTAL TEMPERATURE, DEGREES R

459.31196       MIXTURE VELOCITY AT TUBE ENTRANCE, FT/SEC


SECTION           1
  0.70000       QUALITY AT MIDDLE OF SECTION
  3.16053       LIQUID VELOCITY (FT./SEC.)
406.03216       VAPOR VELOCITY (FT./SEC.)
  1.34772       QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-
  0.46882       DIFFERENTIAL LENGTH OF TUBE, (FT.)
  3.33020       CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R
 11.42571       CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)

SECTION           2
  0.50000       QUALITY AT MIDDLE OF SECTION
  3.05028       LIQUID VELOCITY (FT./SEC.)
286.14649       VAPOR VELOCITY (FT./SEC.)
  1.35884       QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-F
  0.46270       DIFFERENTIAL LENGTH OF TUBE, (FT.)
  2.75045       CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R
  9.61710       CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)

SECTION           3
  0.30000       QUALITY AT MIDDLE OF SECTION
  2.55109       LIQUID VELOCITY (FT./SEC.)
170.81236       VAPOR VELOCITY (FT./SEC.)
  1.36807       QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-F
  0.45839       DIFFERENTIAL LENGTH OF TUBE, (FT.)
  1.90459       CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R
  6.76430       CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)

SECTION           4
  0.10000       QUALITY AT MIDDLE OF SECTION
  1.62361       LIQUID VELOCITY (FT./SEC.)
 58.06430       VAPOR VELOCITY (FT./SEC.)
  1.37449       QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-F
  0.45601       DIFFERENTIAL LENGTH OF TUBE, (FT.)
  0.78596       CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R
  2.82173       CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)


 30.62884       ACCUMULATED SUM OF PRESSURE CHANGE, (PSF)
  1.84591       TOTAL TUBE LENGTH, FT.
4200147.64539       ACCUMULATED SUM OF HEAT LOST, BTU/HR
  0.83150       ACCUMULATED WEIGHT OF TRAPPED LIQUID, LB.
  1.24537       WEIGHT OF ONE TUBE, LBS
577.85264       TOTAL WEIGHT OF UNIT, LBS
  0.00014       WEIGHT PER UNIT OF HEAT TRANSFER, LB-HR/BTU
330.09666       PLANFORM AREA, SQFT

 67.07934       MOMENTUM PRESSURE AT INLET, LBS/SQFT
  4.21459       KINETIC ENERGY OF FLUID AT INLET, BTU/LB
  0.01574       MOMENTUM PRESSURE AT END, LBS/SQFT
  0.00000       KINETIC ENERGY OF FLUID AT END, BTU/LB
 67.06360       CHANGE IN MOMENTUM PRESSURE, LBS/SQFT
```

Fig. B-2. Problem 1, Output Data (464 tubes)

```
POTASSIUM CONDENSER FOR SPACE POWERPLANT

INPUT DATA
      1  3000.00000001 TOTAL WEIGHT FLOW (LB/HR)
      2   464.00000000 NO. OF DUCTS
      3     0.00000000 DUCT PERIMETER (FT) *OPTION
      4     0.00000000 DUCT AREA (SQ FT) *OPTION
      5     0.03120000 EFFECTIVE DIAMETER (FT) *OPTION
      6     2.00000000 NO. OF DUCT SECTIONS
      7     2.00000000 NO. OF FINS
      8    10.00000000 NO OF SUBSECTIONS
      9   490.00000000 INLET PRESSURE (LB/SQ FT)
     10  1620.00000001 FLUID TEMP AT ENTRANCE (R)
     11     0.80000000 WEIGHT FRACTION VAPOR
     12   873.00000001 LATENT HEAT OF FLUID (BTU/LB)
     13     0.21000000 SPECIFIC HEAT OF VAPOR (BTU/LB R)
     14     0.00001210 VISCOSITY OF VAPOR (LB/SEC FT)
     15    39.10000000 MOLECULAR WEIGHT OF FLUID (LB/MOL)
     16     0.93600000 VAPOR COMPRESSIBILITY FACTOR
     17    43.60000000 DENSITY OF LIQUID (LB/CU FT)
     18     0.18300000 SPECIFIC HEAT OF LIQUID (BTU/LB R)
     19     0.00010000 VISCOSITY OF LIQUID (LB/SEC FT)


INPUT DUCT VALUES                                    INPUT DATA NO.
SEC      EFFECT PERIFERAL LENGTH FOR RADIATION (FT)
 1            0.05208000                                   30
 2            0.05208000                                   40
SEC      EFFECT PERIFERAL LENGTH FOR CONVECTION (FT)
 1            0.00000000                                   31
 2            0.00000000                                   41
SEC      RADIATION CONSTANT C1 (BTU/HR SQ FT R**4)
 1          .15410000E-08                                  32
 2          .15410000E-08                                  42
SEC      RADIATION CONSTANT C2 (BTU/HR SQ FT)
 1            0.00000000                                   33
 2            0.00000000                                   43
SEC      CONVECTIVE HEAT TRANSFER COEFF (BTU/HR SQ FT R)
 1            0.00000000                                   34
 2            0.00000000                                   44
SEC      AMBIENT TEMP (R)
 1            0.00000000                                   35
 2            0.00000000                                   45
```

Fig. B-3. Problem 1, Input Data (Program 5-2)

```
POTASSIUM CONDENSER FOR SPACE POWERPLANT

INPUT FIN VALUES                                         INPUT DATA NO.
FIN     RADIATION CONSTANT C1 (BTU/HR SQ FT R**4)
 1          .30820000E-08                                         90
 2          .30820000E-08                                        100
FIN     RADIATION CONSTANT C2 (BTU/HR SQ FT)
 1             0.00000000                                         91
 2             0.00000000                                        101
FIN     CONVECTIVE HEAT TRANSFER COEFF SIDE A (BTU/HR SQ FT R)
 1             0.00000000                                         92
 2             0.00000000                                        102
FIN     CONVECTIVE HEAT TRANSFER COEFF SIDE B (BTU/HR SQ FT R)
 1             0.00000000                                         93
 2             0.00000000                                        103
FIN     AMBIENT TEMP SIDE A (R)
 1             0.00000000                                         94
 2             0.00000000                                        104
FIN     AMBIENT TEMP SIDE B (R)
 1             0.00000000                                         95
 2             0.00000000                                        105
FIN     EFFECT LENGTH (FT)
 1             0.08738520                                         96
 2             0.08738520                                        106


OUTPUT DATA

RELP=  (LIQ) V= FT/SEC   REGP=  (VAP) U= FT/SEC   QS=BTU/SCFT  DX= FT        DELT= R       DP= PSF
  .17590E 03   .11513E 01  .46035E 04  .22064E 03  .13376E 01  .93943E-01  .50029E 00  .17165E 01
  .23453E 03   .12073E 01  .41189E 04  .19740E 03  .13393E 01  .93779E-01  .45918E 00  .15800E 01
  .29317E 03   .12265E 01  .36343E 04  .17425E 03  .13408E 01  .93631E-01  .41611E 00  .14355E 01
  .35180E 03   .12160E 01  .31497E 04  .15118E 03  .13422E 01  .93501E-01  .37100E 00  .12830E 01
  .41043E 03   .11798E 01  .26652E 04  .12819E 03  .13434E 01  .93388E-01  .32369E 00  .11218E 01
  .46907E 03   .11201E 01  .21806E 04  .10523E 03  .13445E 01  .93294E-01  .27393E 00  .95108E 00
  .52770E 03   .10060E 01  .16960E 04  .82361E 02  .13454E 01  .93214E-01  .23824E 00  .82846E 00
  .58634E 03   .97787E 00  .12114E 04  .59079E 02  .13462E 01  .93156E-01  .16992E 00  .59172E 00
  .64497E 03   .87635E 00  .72686E 03  .35785E 02  .13467E 01  .93120E-01  .10394E 00  .36231E 00
  .70360E 03   .59768E 00  .24229E 03  .12344E 02  .13471E 01  .93105E-01  .40798E-01  .14229E 00

DPSUM=  .10013E 02 LB/SQ FT   DPM=  .16766E 02 LB/SQ FT   WLTSUM= .49625E 00 LB
QSUM=  .20960E 07 BTU/HR      UFS=  .22966E 03 FEET/SEC   UFEND=  .53878E-01 FEET/SEC
ELW=  .93413E 00 FEET         PMS=  .16770E 02 LB/SQ FT   PMEND=  .39343E-02 LB/SQ FT
TE=  0.            R          KES=  .10536E 01 BTU/LB     KEEND=  .57992E-07 BTU/LB
```

Fig. B-4. Problem 1, Input and Output Data (Program 5-2)

```
    CALCULATED DATA   120 TUBES

      0.08824       EFFECTIVE LENGTH OF FIN, FT.
      0.00290       ENVIRONMENTAL TEMPERATURF, DEGREES R

   1776.00624       MIXTURE VELOCITY AT TUBE ENTRANCE, FT/SEC


    SECTION           1
      0.70000       QUALITY AT MIDDLE OF SECTION
     20.49243       LIQUID VELOCITY (FT./SEC.)
   1563.46928       VAPOR VELOCITY (FT./SEC.)
      1.34772       QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-F
      2.20429       DIFFERENTIAL LENGTH OF TUBE, (FT.)
    -49.53293       CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R
   -169.94465       CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)

    SECTION           2
      0.50000       QUALITY AT MIDDLE OF SECTION
     18.38761       LIQUID VELOCITY (FT./SEC.)
   1665.73463       VAPOR VELOCITY (FT./SEC.)
      1.19030       QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-F
      2.98780       DIFFERENTIAL LENGTH OF TUBE, (FT.)
   -245.31483       CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R
   -584.97684       CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)
LOW RATE EXCESSIVE, PRESSURE DROP GREATER THAN INLET PRESSURE



    CALCULATED DATA    100 TUBES

      0.08824       EFFECTIVE LENGTH OF FIN, FT.
      0.00290       ENVIRONMENTAL TEMPERATURE, DEGREES R

   2131.20749       MIXTURE VELOCITY AT TUBE ENTRANCE, FT/SEC


    SECTION           1
      0.76000       QUALITY AT MIDDLE OF SECTION
     25.00642       LIQUID VELOCITY (FT./SEC.)
   2034.31417       VAPOR VELOCITY (FT./SEC.)
      1.34772       QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-FT
      1.28358       DIFFERENTIAL LENGTH OF TUBE, (FT.)
    -69.35513       CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R
   -237.95349       CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)
OW RATE EXCESSIVE. GO TO NEXT CASE.
```

Fig. B-5. Problem 1, Output Data (100 and 120 tubes)

```
POTASSIUM REHEATER   CONVECTIVE ENVIRONMENT

        INPUT DATA


   1620.00000      FLUID TEMPERATURE, DEGREES R
    490.00000      FLUID ENTERY PRESSURE,LB/SQFT
   3000.00000      FLOW RATE, LB/HR
      0.80000      WEIGHT FRACTION OF VAPOR

      0.18300      SPECIFIC HEAT OF LIQUID, BTU/LB-DEGREES R
      0.00010      VISCOSITY OF LIQUID, LB/SEC-FT
     43.60000      DENSITY OF LIQUID, LB/CUFT
    873.00000      LATENT HEAT OF FLUID, BTU/LB

      0.21000      SPECIFIC HEAT OF GAS, BTU/LB-DEGREESR
      0.00001      VISCOSITY OF GAS, LB/SEC-FT
     39.10000      MOLECULAR WEIGHT OF GAS, LB/MOL
      0.93600      CORRECTION FACTOR FOR IDEAL GAS FORMULA

      0.03120      INSIDE DIAMETER OF TUBE, FT
      0.05208      OUTSIDE DIAMETER OF TUBE, FT
    464.00000      NUMBER OF TUBES

     51.50000      THERMAL CONDUCTIVITY OF FIN MATERIAL (BTU/FT.HR.R)
      0.00000      FORM FACTOR BETWEEN SIDE A AND MOON
      0.00000      FORM FACTOR BETWEEN SIDE B AND MOON
      0.00000      ABSORBTIVITY, SIDE A
      0.00000      ABSORBTIVITY, SIDE B
      0.00000      EMISSIVITY, SIDE A
      0.00000      EMISSIVITY, SIDE B
      0.00000      FORM FACTOR BETWEEN SIDE A AND X
      0.00000      FORM FACTOR BETWEEN SIDE B AND X
      0.00000      TEMPERATURE OF X (DEGREES R)
      0.00000      ANGLE BETWEEN SUNS RAYS AND NORMAL TO X (DEGREES)
      0.00000      REFLECTIVITY OF X
      0.00000      TEMPERATURE OF MOON (DEGREES R)
      0.00000      ANGLE BETWEEN SUNS RAYS AND NORMAL TO MOON SURFACE (DEGREES)
      0.00000      REFLECTIVITY OF MOON SURFACE
      0.00000      ANGLE BETWEEN SUNS RAYS AND PLANE OF EXTENDED SURFACE
      0.00833      ROOT THICKNESS,              (FEET)
      0.25000      RATIO OF END TO ROOT SECTION
      0.16666      LENGTH OF FIN (FEET)

      2.00000      CONVECTION COEFFICIENT SIDE A (BTU/HR.SQFT.R)
      2.00000      CONVECTION COEFFICIENT SIDE B (BTU/HR.SQFT.R)
   2000.00000      FLUID TEMPERATURE SIDE A (DEGREES R)
   2000.00000      FLUID TEMPERATURE SIDE B (DEGREES R)


      0.00000      X10E-08     C1 (BTU/HR.SQFT.R**4)
      0.00000      C2 (BTU/HR.SQFT.)



 ONDIMENSIONAL PARAMETERS

      0.00000      ZETA P  PROFILE NUMBER
      0.00000      C3 ENVIRONMENTAL PARAMETER
      0.25888      FH  SURFACE CONVECTIVE PARAMETER
      0.31960      FAH  ENVIRONMENT CONVECTIVE PARAMETER
```

Fig. B-6. Problem 2, Input Data

```
CALCULATED DATA

   0.15363      EFFECTIVE LENGTH OF FIN, FT.
2000.00000      ENVIRONMENTAL TEMPERATURE, DEGREES R

 229.65598      MIXTURE VELOCITY AT TUBE ENTRANCE, FT/SEC


 SECTION          1
   0.82500      QUALITY AT MIDDLE OF SECTION
   1.06786      LIQUID VELOCITY (FT./SEC.)
 238.93127      VAPOR VELOCITY (FT./SEC.)
  -0.16427      QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-
   0.47491      DIFFERENTIAL LENGTH OF TUBE, (FT.)
  -1.86657      CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R
  -6.40409      CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)

 SECTION          2
   0.87500      QUALITY AT MIDDLE OF SECTION
   0.94874      LIQUID VELOCITY (FT./SEC.)
 256.02486      VAPOR VELOCITY (FT./SEC.)
  -0.16508      QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-
   0.47268      DIFFERENTIAL LENGTH OF TUBE, (FT.)
  -1.93483      CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R
  -6.56664      CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)

 SECTION          3
   0.92500      QUALITY AT MIDDLE OF SECTION
   0.75141      LIQUID VELOCITY (FT./SEC.)
 273.57835      VAPOR VELOCITY (FT./SEC.)
  -0.16591      QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-
   0.47058      DIFFERENTIAL LENGTH OF TUBE, (FT.)
  -1.93280      CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R
  -6.48621      CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)

 SECTION          4
   0.97500      QUALITY AT MIDDLE OF SECTION
   0.45949      LIQUID VELOCITY (FT./SEC.)
 291.27534      VAPOR VELOCITY (FT./SEC.)
  -0.16675      QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-
   0.46746      DIFFERENTIAL LENGTH OF TUBE, (FT.)
  -2.39970      CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R
  -7.96258      CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)


  -27.41952      ACCUMULATED SUM OF PRESSURE CHANGE, (PSF)
    1.88564      TOTAL TUBE LENGTH, FT.
-521276.30831    ACCUMULATED SUM OF HEAT LOST, BTU/HR
    0.17709      ACCUMULATED WEIGHT OF TRAPPED LIQUID, LB.
    1.27217      WEIGHT OF ONE TUBE, LBS
  590.28833      TOTAL WEIGHT OF UNIT, LBS
   -0.00113      WEIGHT PER UNIT OF HEAT TRANSFER, LB-HR/BTU
  337.20052      PLANFORM AREA, SQFT

   16.76983      MOMENTUM PRESSURE AT INLET, LBS/SQFT
    1.05365      KINETIC ENERGY OF FLUID AT INLET, BTU/LB
   22.09231      MOMENTUM PRESSURE AT END, LBS/SQFT
    1.82860      KINETIC ENERGY OF FLUID AT END, BTU/LB
   -5.32248      CHANGE IN MOMENTUM PRESSURE, LBS/SQFT
```

Fig. B-7. Problem 2, Output Data

```
POTASSIUM CONDENSER CONVECTIVE AND RADIATIVE ENVIRONMENT

         INPUT DATA


    1620.00000     FLUID TEMPERATURE. DEGREES R
     490.00000     FLUID ENTERY PRESSURE,LB/SQFT
    3000.00000     FLOW RATE, LB/HR
       0.80000     WEIGHT FRACTION OF VAPOR

       0.18300     SPECIFIC HEAT OF LIQUID, BTU/LB-DEGREES R
       0.00010     VISCOSITY OF LIQUID, LB/SEC-FT
      43.60000     DENSITY OF LIQUID, LB/CUFT
     873.00000     LATENT HEAT OF FLUID, BTU/LB

       0.21000     SPECIFIC HEAT OF GAS, BTU/LB-DEGREESR
       0.00001     VISCOSITY OF GAS, LB/SEC-FT
      39.10000     MOLECULAR WEIGHT OF GAS, LB/MOL
       0.93600     CORRECTION FACTOR FOR IDEAL GAS FORMULA

       0.03120     INSIDE DIAMETER OF TUBE, FT
       0.05208     OUTSIDE DIAMETER OF TUBE, FT
     464.00000     NUMBER OF TUBES

      51.50000     THERMAL CONDUCTIVITY OF FIN MATERIAL (BTU/FT.HR.R)
       0.00000     FORM FACTOR BETWEEN SIDE A AND MOON
       0.00000     FORM FACTOR BETWEEN SIDE B AND MOON
       0.00000     ABSORBTIVITY, SIDE A
       0.00000     ABSORBTIVITY, SIDE B
       0.00000     EMISSIVITY, SIDE A
       0.00000     EMISSIVITY, SIDE B
       0.00000     FORM FACTOR BETWEEN SIDE A AND X
       0.00000     FORM FACTOR BETWEEN SIDE B AND X
       0.00000     TEMPERATURE OF X (DEGREES R)
       0.00000     ANGLE BETWEEN SUNS RAYS AND NORMAL TO X (DEGREES)
       0.00000     REFLECTIVITY OF X
       0.00000     TEMPERATURE OF MOON (DEGREES R)
       0.00000     ANGLE BETWEEN SUNS RAYS AND NORMAL TO MOON SURFACE (DEGREES)
       0.00000     REFLECTIVITY OF MOON SURFACE
       0.00000     ANGLE BETWEEN SUNS RAYS AND PLANE OF EXTENDED SURFACE
       0.00833     ROOT THICKNESS,            (FEET)
       0.25000     RATIO OF END TO ROOT SECTION
       0.16666     LENGTH OF FIN (FEET)

       2.00000     CONVECTION COEFFICIENT SIDE A (BTU/HR.SQFT.R)
       2.00000     CONVECTION COEFFICIENT SIDE B (BTU/HR.SQFT.R)
    1622.00000     FLUID TEMPERATURE SIDE A (DEGREES R)
    1622.00000     FLUID TEMPERATURE SIDE B (DEGREES R)


       0.05000     X10E-08     C1 (BTU/HR.SQFT.R**4)
       0.00000     C2 (BTU/HR.SQFT.)



 ONDIMENSIONAL PARAMETERS

       0.13758     ZETA P  PROFILE NUMBER
       0.00000     C3 ENVIRONMENTAL PARAMETER
       0.25883     FH  SURFACE CONVECTIVE PARAMETER
       0.25920     FAH  ENVIRONMENT CONVECTIVE PARAMETER
```

Fig. B-8. Problem 3, Input Data

```
   CALCULATED DATA

     0.12773      EFFECTIVE LENGTH OF FIN, FT.
  1298.22747      ENVIRONMENTAL TEMPERATURE, DEGREES R

   229.65598      MIXTURE VELOCITY AT TUBE ENTRANCE, FT/SEC

   SECTION         1
     0.70000      QUALITY AT MIDDLE OF SECTION
     1.19854      LIQUID VELOCITY (FT./SEC.)
   203.68647      VAPOR VELOCITY (FT./SEC.)
     0.29343      QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-F
     1.07253      DIFFERENTIAL LENGTH OF TUBE, (FT.)
    -0.67686      CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R
    -2.32228      CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)

   SECTION         2
     0.50000      QUALITY AT MIDDLE OF SECTION
     1.21605      LIQUID VELOCITY (FT./SEC.)
   147.41722      VAPOR VELOCITY (FT./SEC.)
     0.29269      QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-F
     1.07321      DIFFERENTIAL LENGTH OF TUBE, (FT.)
    -0.20394      CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R
    -0.69698      CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)

   SECTION         3
     0.30000      QUALITY AT MIDDLE OF SECTION
     1.01556      LIQUID VELOCITY (FT./SEC.)
    89.94401      VAPOR VELOCITY (FT./SEC.)
     0.29246      QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-F
     1.07241      DIFFERENTIAL LENGTH OF TUBE, (FT.)
     0.32276      CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R
     1.10173      CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)

   SECTION         4
     0.10000      QUALITY AT MIDDLE OF SECTION
     0.83005      LIQUID VELOCITY (FT./SEC.)
    30.59588      VAPOR VELOCITY (FT./SEC.)
     0.29282      QUANITIES OF HEAT REJECTED PER FOOT OF TUBE LENGTH,(BTU/SEC-F
     1.07086      DIFFERENTIAL LENGTH OF TUBE, (FT.)
     0.08361      CHANGE IN TEMPERATURE PER DIFFERENTIAL LENGTH, (DEGREES R
     0.28594      CHANGE IN PRESSURE PER DIFFERENTIAL LENGTH, (PSF)


    -1.63158      ACCUMULATED SUM OF PRESSURE CHANGE, (PSF)
     4.28901      TOTAL TUBE LENGTH, FT.
2098096.33713      ACCUMULATED SUM OF HEAT LOST, BTU/HR
     2.17501      ACCUMULATED WEIGHT OF TRAPPED LIQUID, LB.
     2.89364      WEIGHT OF ONE TUBE, LBS
  1342.64905      TOTAL WEIGHT OF UNIT, LBS
     0.00064      WEIGHT PER UNIT OF HEAT TRANSFER, LB-HR/BTU
   766.98442      PLANFORM AREA, SQFT

    16.76983      MOMENTUM PRESSURE AT INLET, LBS/SQFT
     1.05365      KINETIC ENERGY OF FLUID AT INLET, BTU/LB
     0.00393      MOMENTUM PRESSURE AT END, LBS/SQFT
     0.00000      KINETIC ENERGY OF FLUID AT END, BTU/LB
    16.76590      CHANGE IN MOMENTUM PRESSURE, LBS/SQFT
```

Fig. B-9. Problem 3, Output Data

```
TUBULAR EVAPORATOR

INPUT DATA
       1      2.50000000 TOTAL WEIGHT FLOW (LB/HR)
       2      1.00000000 NO. OF DUCTS
       3      0.00000000 DUCT PERIMETER (FT) *OPTION
       4      0.00000000 DUCT AREA (SQ FT) *OPTION
       5      0.01925000 EFFECTIVE DIAMETER (FT) *OPTION
       6      1.00000000 NO. OF DUCT SECTIONS
       7      0.00000000 NO. OF FINS
       8     10.00000000 NO OF SUBSECTIONS
       9   1659.74000001 INLET PRESSURE (LB/SQ FT)
      10    660.00000000 FLUID TEMP AT ENTRANCE (R)
      11      0.00000000 WEIGHT FRACTION VAPOR
      12    977.90000001 LATENT HEAT OF FLUID (BTU/LB)
      13      0.35000000 SPECIFIC HEAT OF VAPOR (BTU/LB R)
      14      0.00000849 VISCOSITY OF VAPOR (LB/SEC FT)
      15     18.00000000 MOLECULAR WEIGHT OF FLUID (LB/MOL)
      16      1.00000000 VAPOR COMPRESSIBILITY FACTOR
      17     60.30000000 DENSITY OF LIQUID (LB/CU FT)
      18      1.00500000 SPECIFIC HEAT OF LIQUID (BTU/LB R)
      19      0.00020520 VISCOSITY OF LIQUID (LB/SEC FT)


INPUT DUCT VALUES                                   INPUT DATA NO.
SEC       EFFECT PERIFERAL LENGTH FOR RADIATION (FT)
 1             0.09817000                                 30
SEC       EFFECT PERIFERAL LENGTH FOR CONVECTION (FT)
 1             0.09817000                                 31
SEC       RADIATION CONSTANT C1 (BTU/HR SQ FT R**4)
 1          .13700000E-08                                 32
SEC       RADIATION CONSTANT C2 (BTU/HR SQ FT)
 1          1028.00000001                                 33
SEC       CONVECTIVE HEAT TRANSFER COEFF (BTU/HR SQ FT R)
 1             1.30000000                                 34
SEC       AMBIENT TEMP (R)
 1           925.00000001                                 35
```

Fig. B-10. Problem 4, Input Data

```
TUBULAR EVAPORATOR
                                        2.5 LB/HR FLOW RATE

OUTPUT DATA

RELP=  (LIQ) V= FT/SEC     REGP=  (VAP) U= FT/SEC     QS=BTU/SCFT  DX= FT       DELT= R       DP= PSF
  .21265E 03   .24139E 00   .27041E 03   .48201E 01  -.30339E-01   .22379E 01  -.22894E-01  -.77369E 00
  .19026E 03   .31780E 00   .81124E 03   .13659E 02  -.30340E-01   .22373E 01  -.46693E-01  -.15774E 01
  .16788E 03   .35255E 00   .13521E 04   .22247E 02  -.30344E-01   .22368E 01  -.66794E-01  -.22546E 01
  .14550E 03   .36747E 00   .18929E 04   .30709E 02  -.30349E-01   .22362E 01  -.85130E-01  -.28702E 01
  .12311E 03   .43855E 00   .24337E 04   .38699E 02  -.30356E-01   .22343E 01  -.18367E 00  -.61833E 01
  .10073E 03   .41998E 00   .29745E 04   .47105E 02  -.30370E-01   .22328E 01  -.24080E 00  -.80807E 01
  .78344E 02   .38895E 00   .35154E 04   .55530E 02  -.30389E-01   .22311E 01  -.30127E 00  -.10068E 02
  .55960E 02   .34270E 00   .40562E 04   .63992E 02  -.30413E-01   .22292E 01  -.36348E 00  -.12083E 02
  .33576E 02   .27516E 00   .45970E 04   .72482E 02  -.30441E-01   .22272E 01  -.42410E 00  -.14009E 02
  .11192E 02   .16654E 00   .51378E 04   .80864E 02  -.30474E-01   .22251E 01  -.47221E 00  -.15483E 02

DPSUM= -.73382E 02 LB/SQ FT    DPM= -.62919E 01 LB/SQ FT    WLTSUM= .23761E-01 LB
QSUM= -.24421E 04 BTU/HR       UFS=  .39570E-01 FEET/SEC    UFEND=  .84869E 02 FEET/SEC
ELW=  .22328E 02 FEET          PMS=  .29350E-02 LB/SQ FT    PMEND=  .62948E 01 LB/SQ FT
TE=   .92942E 03 R             KES=  .31281E-07 BTU/LB      KEEND=  .14389E 00 BTU/LB


                                        10 LB/HR FLOW RATE
OUTPUT DATA

RELP=  (LIQ) V= FT/SEC     REGP=  (VAP) U= FT/SEC     QS=BTU/SCFT  DX= FT       DELT= R       DP= PSF
  .85060E 03   .96556E 00   .10816E 04   .19280E 02  -.30339E-01   .89213E 01  -.36518E 00  -.12341E 02
  .76106E 03   .15898E 01   .32449E 04   .53718E 02  -.30367E-01   .88134E 01  -.16069E 01  -.53960E 02
  .67152E 03   .21479E 01   .54082E 04   .89467E 02  -.30493E-01   .86677E 01  -.31951E 01  -.10429E 03
  .58199E 03   .24415E 01   .75715E 04   .13155E 03  -.30741E-01   .84533E 01  -.55961E 01  -.17237E 03
  .49245E 03   .26136E 01   .97348E 04   .18790E 03  -.31171E-01   .81322E 01  -.94909E 01  -.26297E 03
  .40291E 03   .28382E 01   .11898E 05   .28039E 03  -.31887E-01   .75867E 01  -.17309E 02  -.39530E 03
  .31338E 03   .33627E 01   .14061E 05   .51142E 03  -.33151E-01   .62914E 01  -.41853E 02  -.63096E 03
  .22384E 03   .14669E 02   .16225E 05   .12975E 05  -.35998E-01   .31883E 00  -.21369E 04  -.15490E 04
FLOW RATE EXCESSIVE.
P= -.15215E 04 PSF
DPSUM= -.31812E 04 PSF
```

Fig. B-11. Problem 4, Output Data

```
                         CONDENSER WITH NONCIRCULAR DUCT

INPUT DATA
        1       1.50000000 TOTAL WEIGHT FLOW (LB/HR)
        2       1.00000000 NO. OF DUCTS
        3       0.05180000 DUCT PERIMETER (FT) *OPTION
        4       0.00011100 DUCT AREA (SQ FT) *OPTION
        5       0.00000000 EFFECTIVE DIAMETER (FT) *OPTION
        6       1.00000000 NO. OF DUCT SECTIONS
        7       2.00000000 NO. OF FINS
        8      10.00000000 NO OF SUBSECTIONS
        9    1659.74000001 INLET PRESSURE (LB/SQ FT)
       10     660.00000000 FLUID TEMP AT ENTRANCE (R)
       11       1.00000000 WEIGHT FRACTION VAPOR
       12     977.90000001 LATENT HEAT OF FLUID (BTU/LB)
       13       0.35000000 SPECIFIC HEAT OF VAPOR (BTU/LB R)
       14       0.00000849 VISCOSITY OF VAPOR (LB/SEC FT)
       15      18.00000000 MOLECULAR WEIGHT OF FLUID (LB/MOL)
       16       1.00000000 VAPOR COMPRESSIBILITY FACTOR
       17      60.30000000 DENSITY OF LIQUID (LB/CU FT)
       18       1.00500000 SPECIFIC HEAT OF LIQUID (BTU/LB R)
       19       0.00020520 VISCOSITY OF LIQUID (LB/SEC FT)


INPUT DUCT VALUES                                        INPUT DATA NO.
SEC       EFFECT PERIFERAL LENGTH FOR RADIATION (FT)
 1             0.03040000                                      30
SEC       EFFECT PERIFERAL LENGTH FOR CONVECTION (FT)
 1             0.03650000                                      31
SEC       RADIATION CONSTANT C1 (BTU/HR SQ FT R**4)
 1           .14560000E-08                                     32
SEC       RADIATION CONSTANT C2 (BTU/HR SQ FT)
 1            88.61000000                                      33
SEC       CONVECTIVE HEAT TRANSFER COEFF (BTU/HR SQ FT R)
 1             0.00000000                                      34
SEC       AMBIENT TEMP (R)
 1             0.00000000                                      35

INPUT FIN VALUES
FIN       RADIATION CONSTANT C1 (BTU/HR SQ FT R**4)
 1           .14560000E-08                                     90
 2           .14560000E-08                                    100
FIN       RADIATION CONSTANT C2 (BTU/HR SQ FT)
 1            88.61000000                                      91
 2            88.61000000                                     101
FIN       CONVECTIVE HEAT TRANSFER COEFF SIDE A (BTU/HR SQ FT R)
 1             0.00000000                                      92
 2             0.00000000                                     102
FIN       CONVECTIVE HEAT TRANSFER COEFF SIDE B (BTU/HR SQ FT R)
 1             0.00000000                                      93
 2             0.00000000                                     103
FIN       AMBIENT TEMP SIDE A (R)
 1             0.00000000                                      94
 2             0.00000000                                     104
FIN       AMBIENT TEMP SIDE B (R)
 1             0.00000000                                      95
 2             0.00000000                                     105
FIN       EFFECT LENGTH (FT)
 1             0.15590000                                      96
 2             0.15590000                                     106
```

Fig. B-12. Problem 5, Input Data

```
   CONDENSER WITH NONCIRCULAR DUCT
                                         1.5 LB/HR FLOW RATE

OUTPUT DATA

                                                                                         DP= PSF
RELP=  (LIQ) V= FT/SEC    REGP=  (VAP) U= FT/SEC     QS=BTU/SCFT  DX= FT        DELT= R
  .78399E 01    .22441E 00    .35990E 04    .12335F 03    .17838E-01    .23087E 01  -.25222E 01  -.85237E 02
  .23520E 02    .38927E 00    .32202E 04    .11710F 03    .17439E-01    .23661E 01  -.25976E 01  -.83919E 02
  .39200E 02    .50089E 00    .28413E 04    .10950F 03    .17033E-01    .24257E 01  -.25356E 01  -.78165E 02
  .54879E 02    .58316E 00    .24625E 04    .10042F 03    .16641E-01    .24844E 01  -.23719E 01  -.69823E 02
  .70559E 02    .64243E 00    .20836E 04    .89643F 02    .16278E-01    .25391E 01  -.21118E 01  -.59525E 02
  .86239E 02    .63916E 00    .17048E 04    .77303F 02    .15959E-01    .25748E 01  -.11157E 01  -.30251E 02
  .10192E 03    .64103E 00    .13259E 04    .62097E 02    .15791E-01    .26010E 01  -.98384E 00  -.26136E 02
  .11760E 03    .61661E 00    .94710E 03    .45848E 02    .15644E-01    .26230E 01  -.81335E 00  -.21221E 02
  .13328E 03    .55493E 00    .56826E 03    .28564F 02    .15523E-01    .26394E 01  -.59508E 00  -.15296E 02
  .14896E 03    .41652E 00    .18942E 03    .10159E 02    .15435E-01    .26478E 01  -.30193E 00  -.76765E 01

DPSUM= -.47725E 03 LB/SQ FT    DPM=  .14933E 02 LB/SQ FT    WLTSUM= .10013E-01 LB
QSUM=  .14813E 04 BTU/HR       UFS=  .12804E 03 FEET/SEC    UFEND=  .62251E-01 FEET/SEC
ELW=  .25210E 02 FEET          PMS=  .14940E 02 LB/SQ FT    PMEND=  .72638E-02 LB/SQ FT
TE=   .49668E 03 R             KES=  .32751E 00 BTU/LB      KEEND=  .77417E-07 BTU/LB

                                          2 LB/HR FLOW RATE

OUTPUT DATA

                                                                                         DP= PSF
RELP=  (LIQ) V= FT/SEC    REGP=  (VAP) U= FT/SEC     QS=BTU/SCFT  DX= FT        DELT= R
  .10453E 02    .33453E 00    .47987E 04    .16422F 03    .17838E-01    .31177E 01  -.56621E 01  -.19135E 03
  .31360E 02    .58550E 00    .42935E 04    .16615F 03    .16949E-01    .33098E 01  -.67534E 01  -.20543E 03
  .52266E 02    .76943E 00    .37884E 04    .16968E 03    .15917E-01    .35643E 01  -.81075E 01  -.21656E 03
  .73173E 02    .92381E 00    .32833E 04    .17607E 03    .14721E-01    .39196E 01  -.10168E 02  -.23078E 03
  .94079E 02    .10644E 01    .27782E 04    .18881E 03    .13284E-01    .44779E 01  -.14072E 02  -.25705E 03
  .11499E 03    .12161E 01    .22731E 04    .22109F 03    .11406E-01    .56568E 01  -.25437E 02  -.33293E 03
  .13589E 03    .14916E 01    .17679E 04    .40751E 03    .83249E-02    .13651E 02  -.13636E 03  -.78451E 03
FLOW RATE EXCESSIVE.
P= -.55887E 03 PSF
DPSUM= -.22186E 04 PSF
```

Fig. B-13. Problem 5, Output Data

```
                    MULTI FIN FREON CONDENSER

INPUT DATA
       1    75.00000000 TOTAL WEIGHT FLOW (LB/HR)
       2     1.00000000 NO. OF DUCTS
       3     0.00000000 DUCT PERIMETER (FT) *OPTION
       4     0.00000000 DUCT AREA (SQ FT) *OPTION
       5     0.03750000 EFFECTIVE DIAMETER (FT) *OPTION
       6     3.00000000 NO. OF DUCT SECTIONS
       7     3.00000000 NO. OF FINS
       8    10.00000000 NO OF SUBSECTIONS
       9  3157.90000001 INLET PRESSURE (LB/SQ FT)
      10   600.00000000 FLUID TEMP AT ENTRANCE (R)
      11     1.00000000 WEIGHT FRACTION VAPOR
      12    61.31000000 LATENT HEAT OF FLUID (BTU/LB)
      13     0.16100000 SPECIFIC HEAT OF VAPOR (BTU/LB R)
      14     0.00000746 VISCOSITY OF VAPOR (LB/SEC FT)
      15   187.39000000 MOLECULAR WEIGHT OF FLUID (LB/MOL)
      16     0.95000000 VAPOR COMPRESSIBILITY FACTOR
      17    92.33000000 DENSITY OF LIQUID (LB/CU FT)
      18     0.21800000 SPECIFIC HEAT OF LIQUID (BTU/LB R)
      19     0.00029702 VISCOSITY OF LIQUID (LB/SEC FT)


INPUT DUCT VALUES                                         INPUT DATA NO.
SEC      EFFECT PERIFERAL LENGTH FOR RADIATION (FT)
 1             0.03375000                                        30
 2             0.00000000                                        40
 3             0.03375000                                        50
SEC      EFFECT PERIFERAL LENGTH FOR CONVECTION (FT)
 1             0.03375000                                        31
 2             0.00000000                                        41
 3             0.03375000                                        51
SEC      RADIATION CONSTANT C1 (BTU/HR SQ FT R**4)
 1          .14560000E-08                                        32
 2          0.                                                   42
 3          0.                                                   52
SEC      RADIATION CONSTANT C2 (BTU/HR SQ FT)
 1           146.10000000                                        33
 2             0.00000000                                        43
 3             0.00000000                                        53
SEC      CONVECTIVE HEAT TRANSFER COEFF (BTU/HR SQ FT R)
 1             7.00000000                                        34
 2             0.00000000                                        44
 3            12.00000000                                        54
SEC      AMBIENT TEMP (R)
 1           530.00000000                                        35
 2             0.00000000                                        45
 3           500.00000000                                        55
```

Fig. B-14. Problem 6, Input Data

```
MULTI FIN FREON CONDENSER

INPUT FIN VALUES                                                   INPUT DATA NO.
FIN       RADIATION CONSTANT C1 (BTU/HR SQ FT R**4)
 1           .14560000E-08                                              90
 2           .14560000E-08                                             100
 3          0.                                                         110
FIN       RADIATION CONSTANT C2 (BTU/HR SQ FT)
 1            146.10000000                                              91
 2            146.10000000                                             101
 3              0.00000000                                             111
FIN       CONVECTIVE HEAT TRANSFER COEFF SIDE A (BTU/HR SQ FT R)
 1              7.00000000                                              92
 2              7.00000000                                             102
 3             12.00000000                                             112
FIN       CONVECTIVE HEAT TRANSFER COEFF SIDE B (BTU/HR SQ FT R)
 1             12.00000000                                              93
 2              0.00000000                                             103
 3              0.00000000                                             113
FIN       AMBIENT TEMP SIDE A (R)
 1            530.00000000                                              94
 2            530.00000000                                             104
 3            500.00000000                                             114
FIN       AMBIENT TEMP SIDE B (R)
 1            500.00000000                                              95
 2              0.00000000                                             105
 3              0.00000000                                             115
FIN       EFFECT LENGTH (FT)
 1              0.18600000                                              96
 2              0.34900000                                             106
 3              0.29520000                                             116
```

Fig. B-14. Problem 6, Input Data (con't)

```
MULTI FIN FREON CONDENSER
                                        75 LB/HR FLOW RATE

OUTPUT DATA

RELP=  (LIQ) V= FT/SEC     REGP=  (VAP) U= FT/SEC     QS=BTU/SCFT  DX= FT          DELT= R         DP= PSF
  .11908E 03    .55195E 00    .90079E 05    .27153E 02    .25579E 00    .49961E 00    .40505E-02    .21652E 00
  .35723E 03    .98849E 00    .80597E 05    .24607E 02    .25581E 00    .49955E 00    .35088E-02    .18757E 00
  .59538E 03    .12890E 01    .71115E 05    .21905E 02    .25582E 00    .49948E 00    .34675E-02    .18537E 00
  .83353E 03    .15177E 01    .61633E 05    .19133E 02    .25583E 00    .49940E 00    .38266E-02    .20458E 00
  .10717E 04    .15745E 01    .52151E 05    .16382E 02    .25584E 00    .49931E 00    .44581E-02    .23835E 00
  .13098E 04    .15356E 01    .42669E 05    .13617E 02    .25585E 00    .49924E 00    .48097E-02    .25717E 00
  .15480E 04    .14378E 01    .33187E 05    .10814E 02    .25587E 00    .49918E 00    .48604E-02    .25989E 00
  .17861E 04    .12804E 01    .23705E 05    .79632E 01    .25588E 00    .49913E 00    .46399E-02    .24812E 00
  .20243E 04    .98526E 00    .14223E 05    .51057E 01    .25589E 00    .49919E 00   -.16282E-02   -.87072E-01
  .22624E 04    .66044E 00    .47410E 04    .19854E 01    .25589E 00    .49912E 00    .23800E-02    .12728E 00

DPSUM=  .18378E 01 LB/SQ FT   DPM=  .16329E 02 LB/SQ FT   WLTSUM= .48360E-01 LB
QSUM=  .45990E 04 BTU/HR      UFS=  .28053E 02 FEET/SEC   UFEND=  .20430E 00 FEET/SEC
ELW=  .49932E 01 FEET         PMS=  .16449E 02 LB/SQ FT   PMEND=  .11979E 00 LB/SQ FT
TE=   .51423E 03 R            KES=  .15722E-01 BTU/LB     KEEND=  .83381E-06 BTU/LB

                                        225 LB/HR FLOW RATE
OUTPUT DATA

RELP=  (LIQ) V= FT/SEC     REGP=  (VAP) U= FT/SEC     QS=BTU/SCFT  DX= FT          DELT= R         DP= PSF
  .35723E 03    .24930E 01    .27024E 06    .80947E 02    .25579E 00    .15282E 01   -.53517E 00   -.28607E 02
  .10717E 04    .41701E 01    .24179E 06    .73751E 02    .25418E 00    .15360E 01   -.49815E 00   -.26434E 02
  .17861E 04    .52342E 01    .21334E 06    .66063E 02    .25267E 00    .15415E 01   -.43211E 00   -.22774E 02
  .25006E 04    .52498E 01    .18490E 06    .58332E 02    .25137E 00    .15677E 01   -.85454E 00   -.44772E 02
  .32150E 04    .53723E 01    .15645E 06    .50567E 02    .24879E 00    .15802E 01   -.77636E 00   -.40199E 02
  .39295E 04    .49010E 01    .12801E 06    .42658E 02    .24644E 00    .15896E 01   -.65869E 00   -.33742E 02
  .46439E 04    .43675E 01    .99561E 05    .34347E 02    .24446E 00    .15958E 01   -.52462E 00   -.26630E 02
  .53584E 04    .37514E 01    .71115E 05    .25617E 02    .24287E 00    .15985E 01   -.37857E 00   -.19077E 02
  .60728E 04    .30154E 01    .42669E 05    .16400E 02    .24173E 00    .15978E 01   -.22556E 00   -.11307E 02
  .67873E 04    .20131E 01    .14223E 05    .63848E 01    .24105E 00    .15932E 01   -.62511E-01   -.31239E 01

DPSUM= -.25667E 03 LB/SQ FT   DPM=  .14696E 03 LB/SQ FT   WLTSUM= .14588E 00 LB
QSUM=  .14034E 05 BTU/HR      UFS=  .84160E 02 FEET/SEC   UFEND=  .61289E 00 FEET/SEC
ELW=  .15729E 02 FEET         PMS=  .14804E 03 LB/SQ FT   PMEND=  .10781E 01 LB/SQ FT
TE=   .51423E 03 R            KES=  .14150E 00 BTU/LB     KEEND=  .75043E-05 BTU/LB
```

Fig. B-15. Problem 6, Output Data